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THE KINEMATIC VARIABLES RELATED TO THE EFFICIENCY OF THROWING: FOOTBALL

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By

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Abstract

THE KINEMATIC VARIABLES RELATED TO THE EFFICIENCY OF THROWING: FOOTBALL

by Robert A. Heppe

Specific to throwing a football, limited data are available to compare similarities or differences among the various types of possible passes or between the other overarm throwing/striking skills.

The present study reported the kinematic variables associated with throwing a football, and attempted to gain insight into the relationship between lateral stride foot placement and accuracy. Four division I-A quarterbacks were used in the study.

The kinematic variables calculated were similar to those in recently articles with the exception of hip and shoulder angular velocity. Hip and shoulder movement maybe subject to individual differences within the overarm throwing pattern. No correlation was found between lateral stride foot placement and accuracy, although a recommendation to increase this distance (approximately eight inches in this study) was made to allow the net force to be translated forward in a more linear fashion and to allow for more complete hip rotation.

Acknowledgements

Many thank yous and acknowledgements are deserved because in the words of Robert H. Schuller, in the final analysis the goalsetter humbly knows and is the first to admit that others made it happen.

First, huge thanks to Dr. Gail Evans, Dr. Bethany Shifflett, and Dr. Susan Wilkinson who provided outstanding instruction, emotional and personal support, and academic challenges throughout my undergraduate and graduate career. Thanks for believing in me and pushing me to do what I was capable of!

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Saving the largest thanks for last, I want to thank my entire family who have supported me in every possible way. I wish to thank my parents for giving me the opportunity and all the help I needed. Also, thanks to Grandpa and Grandma Jorgenson and the very special Grandpa Heppe who unfortunately was unable to see the completion of this project.

A special thank you to Dr. Greg Rash whose computer program was an essential part of the analysis of data segment of this project.

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CHAPTER I

Introduction

The overarm throwing pattern is used in a wide variety of sport skills. Examples can be seen in track and field (javelin throwing), court games (spiking a volleyball and smashing in badminton), and field sports (football and baseball). The throwing pattern is described by Toyoshima, Hoshikawa, Miyashita, and Oguri (1974) as a general movement pattern characterized by rotation of the hips, trunk, and shoulder girdle, and extension of the elbow and flexion of the wrist. The aforementioned skills are governed by the general characteristics of the overarm throwing movement, but each skill is a unique variation of that general pattern because of the demands related to their different environments. Within the general movement pattern variations in range of motion (ROM), velocities, accelerations, and planes of motion of the individual segments can be observed depending on the constraints encountered and the objectives of the sport or activity.

Movement is governed by the law of specificity or the SAID (specific adaptations to imposed demands) principle. The objectives, constraints, and environment present for one to successfully complete a badminton smash, for example, are different than those encountered by a baseball pitcher trying to throw a strike. The badminton smash and a baseball pitch, however, rely on the execution of similar general movement patterns that are, in fact, specific to the skill. Research on the general movement pattern of throwing has been presented by Adrian and Cooper (1989), Atwater (1970, 1979), Lindner (1971), Toyoshima et al. (1974), Kreighbaum and Barthels (1990), and Tullos and King (1973). Research into the specific skills related to the general throwing pattern has begun. Studies on baseball pitching (Elliott, Grove, & Gibson, 1988; Feltner, 1984, 1987, 1989; Jobe, Tibone, Perry, & Moynes, 1983, 1984; Michaud, 1990; Papas, Zawacki, & Sullivan, 1985), javelin throwing (Komi & Mero 1985, Menzel 1987), and the badminton smash

(Gowitzke & Waddell 1979) have been completed, but there has been little published research on the football throw. Another example of the lack of football's uniqueness can be found in Kreighbaum and Barthel's (1990) textbook, Biomechanics: A Qualitative Approach for Studying Human Movement, where references are cited for each specific variation of the throwing pattern except for throwing a football. The authors also fail to categorize throwing a football under any movement pattern (underarm, sidearm, or overarm). Typically biomechanics literature has non-specifically associated throwing a football with certain types of baseball throws. Although throwing a football may have some similarities to the type of throwing a baseball short-stop does, (i.e., throwing while moving; throwing while off balance), the football throw has very different constraints, objectives, and environment.

The placement of the stride foot (on or off the midline between the thrower and the intended target) and its relationship to force production and the accuracy of the throw has experienced some contradiction. Hinkle (1979), in an article that applied the laws of physics to throwing a football, stated that the stride foot should land on the midline between the quarterback and receiver in order for maximum force to be produced and for the throw to be accurate. In Atwater's (1970) study of skilled and unskilled throwers subjects were also found to stride on the midline between the thrower and the target. Conversely, Hay (1985) in his textbook, The Biomechanics of Sports Techniques, stated that the stride foot should take an off-line placement between the thrower and the target. Verduzco (1991) in his case study of the football throw and model for throwing a football agreed with the off-line placement of the stride foot reported in Hay's textbook. Hay (1985) added that, "This off-line placement of the striding foot permits the hips to be more completely rotated to the front than if the foot were placed on line" (p.194).

Carlson (1962) stressed the importance of stride foot placement by stating that

> the left foot is the focal point for direction, to hit the receiver, whether he is moving at an angle, hooking, or stationary, (and that) the left foot of the passer is instrumental in acquiring the proper alignment of his body toward the target (p. 14).

Statement of the Problem

Throwing a football has been typically, and perhaps erroneously, categorized with pitching or the long throws of an outfielder in baseball. By the very nature of the game, football has a unique set of performance constraints, objectives, and conditions. For example, the environment for throwing a football is unpredictable. The initial and final alignment of the defensive players in which the throw is made is not constant. Additionally, the constraints and objectives of which target to throw to and how to get the ball there continually change. Lastly, the size and mass of the projectile used and the time available are not comparable to baseball. Throwing the football needs to be studied as a specific skill in relation to the general movement pattern of overarm throwing.

Definitions

Abducted position at the shoulder joint. "Any position of the upper arm where the elbow joint was above shoulder level" (Feltner, 1987, p. 6) (See Figure 1a).

Abduction at the shoulder joint. An upward rotation of the upper arm, away from the midsaggital plane of the body, in the frontal plane (Kendall & M^cKreary, 1983) (See Figure 1b).

Adducted position at the shoulder joint. "Any position of the upper arm where the elbow joint was below shoulder level" (Feltner, 1987, p. 6) (See Figure 1a).

Adduction at the shoulder joint. A downward rotation of the upper arm, toward or beyond the midsaggital plane of the body, in the frontal plane (Kendall & M^cKreary, 1983) (See Figure 1b).

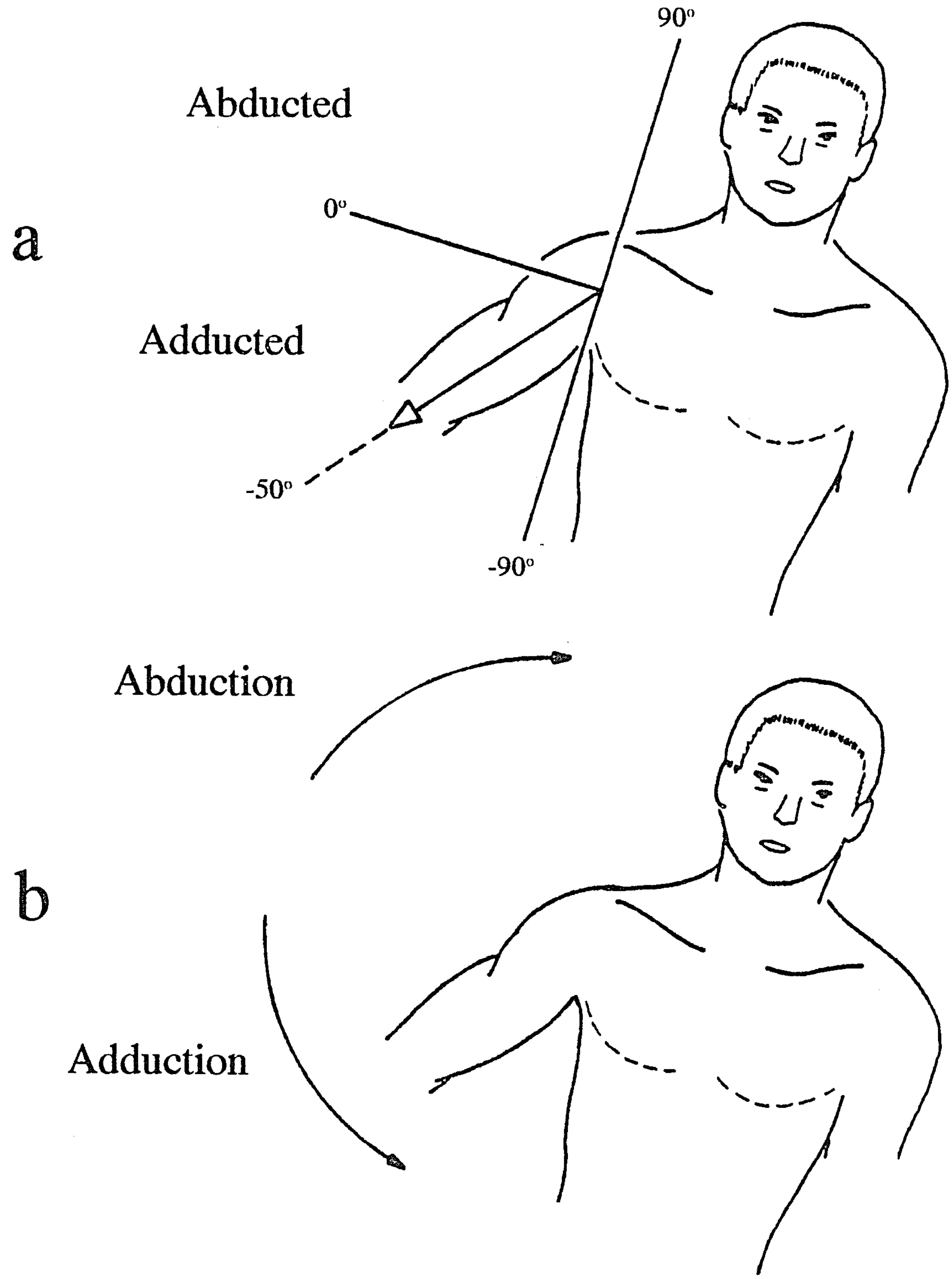


Figure 1. (a) Abducted/adducted positions (Feltner, 1987), and (b) abduction/adduction of the upper arm at the shoulder joint (Feltner, 1987).

Angular Velocity. Angular displacement per unit of time over more than two consecutive fields of movement.

Extension at the elbow joint. "A rotation in which the angle between the upper arm and forearm segments increased" (Feltner, 1987, p. 8) (See Figure 2a).

External rotation at the shoulder joint. "A rotation about the longitudinal axis of the humerus that makes the hand move backward and downward when the elbow is in a flexed position" (Feltner, 1987, p. 8) (See Figure 3b).

Externally rotated position at the shoulder joint. "Any position of the upper arm where, if the upper arm was placed in the position of 0^{o} abduction/adduction and 0^{o} horizontal abduction/adduction with the elbow joint flexed, the wrist joint was posterior to the frontal plane of the body (as viewed from the side)" (Feltner, 1987, p. 8) (See Figure 3a).

Flexion at the elbow joint. "A rotation in which the angle between the upper arm and the forearm segments decreases" (Feltner, 1987, p. 8) (See Figure 2a).

Horizontal abduction at the shoulder joint. "A rotation of the upper arm away from the midsaggital plane of the body, in a neutral (0^{o}) position of abduction/adduction" (Feltner, 1987, p. 8) (See Figure 4a).

Horizontal adduction at the shoulder joint. "A rotation of the upper arm toward or beyond the midsaggital plane of the body, in a neutral (0^{o}) position of abduction/adduction" (Feltner, 1987, p. 8) (See Figure 4a).

Horizontally abducted position at the shoulder joint. "Any position of the upper arm where the elbow joint was posterior to the frontal plane of the body" (Feltner, 1987, p. 12) (See Figure 4b).

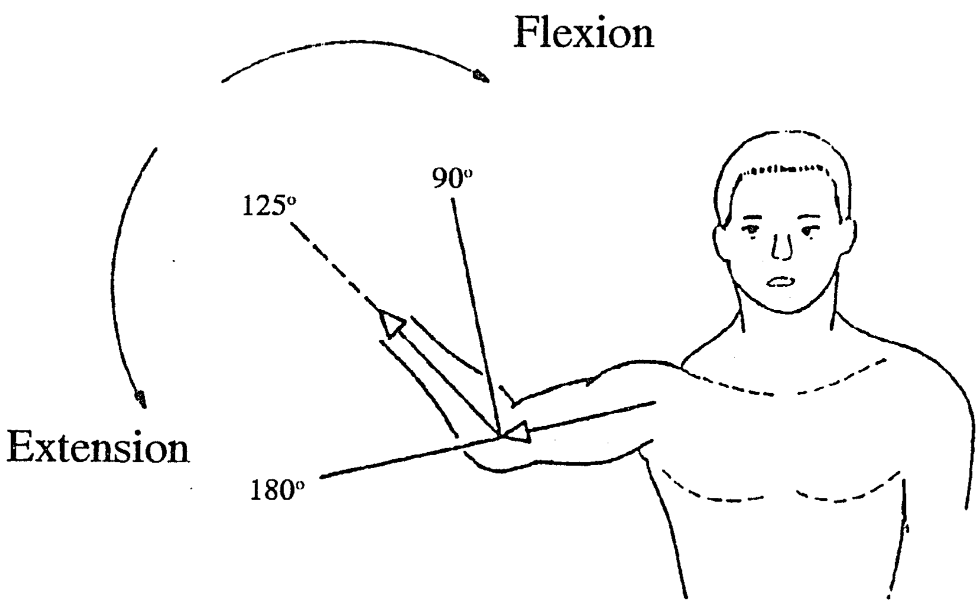
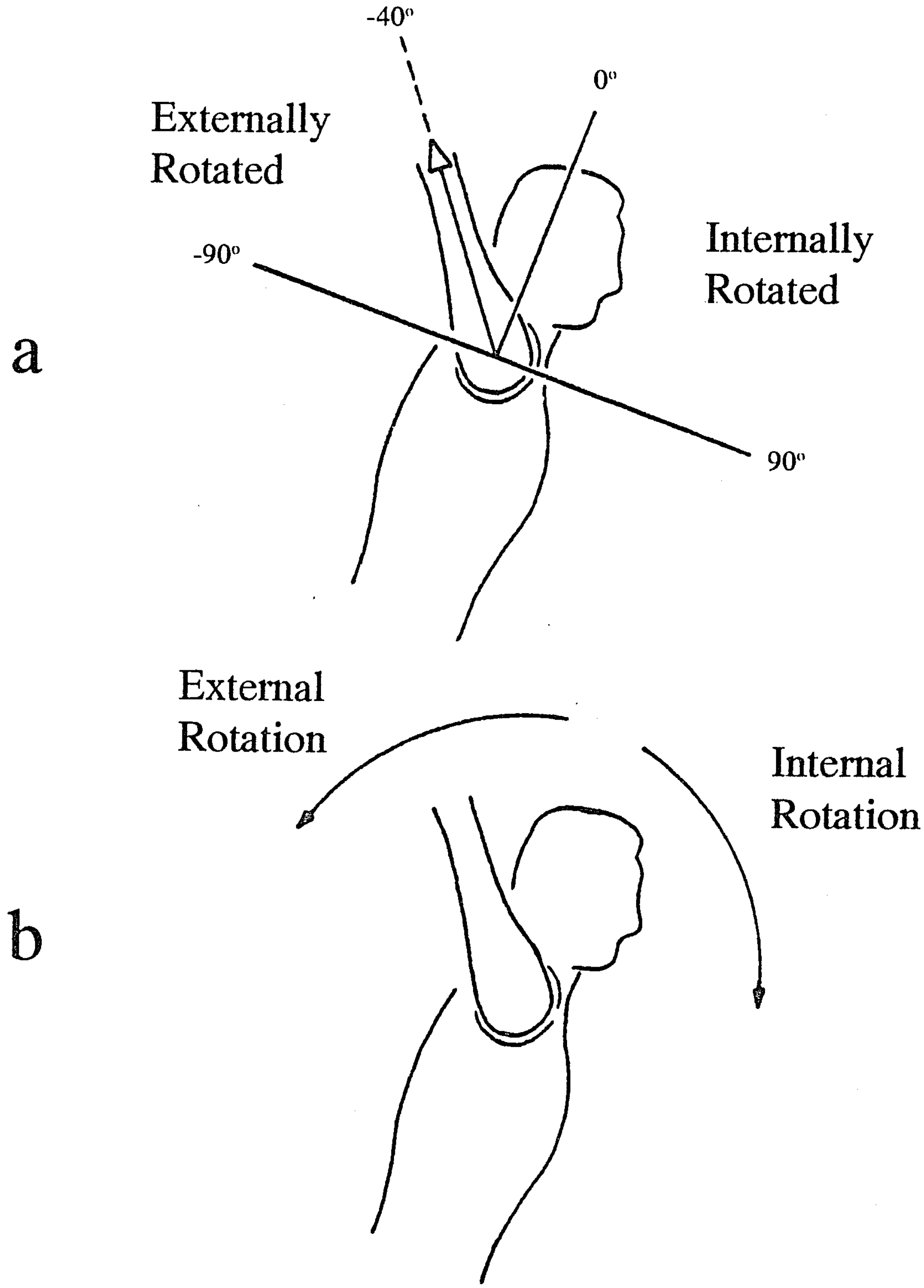


Figure 2. (a) Flexion/extension at the elbow joint (Feltner, 1987).



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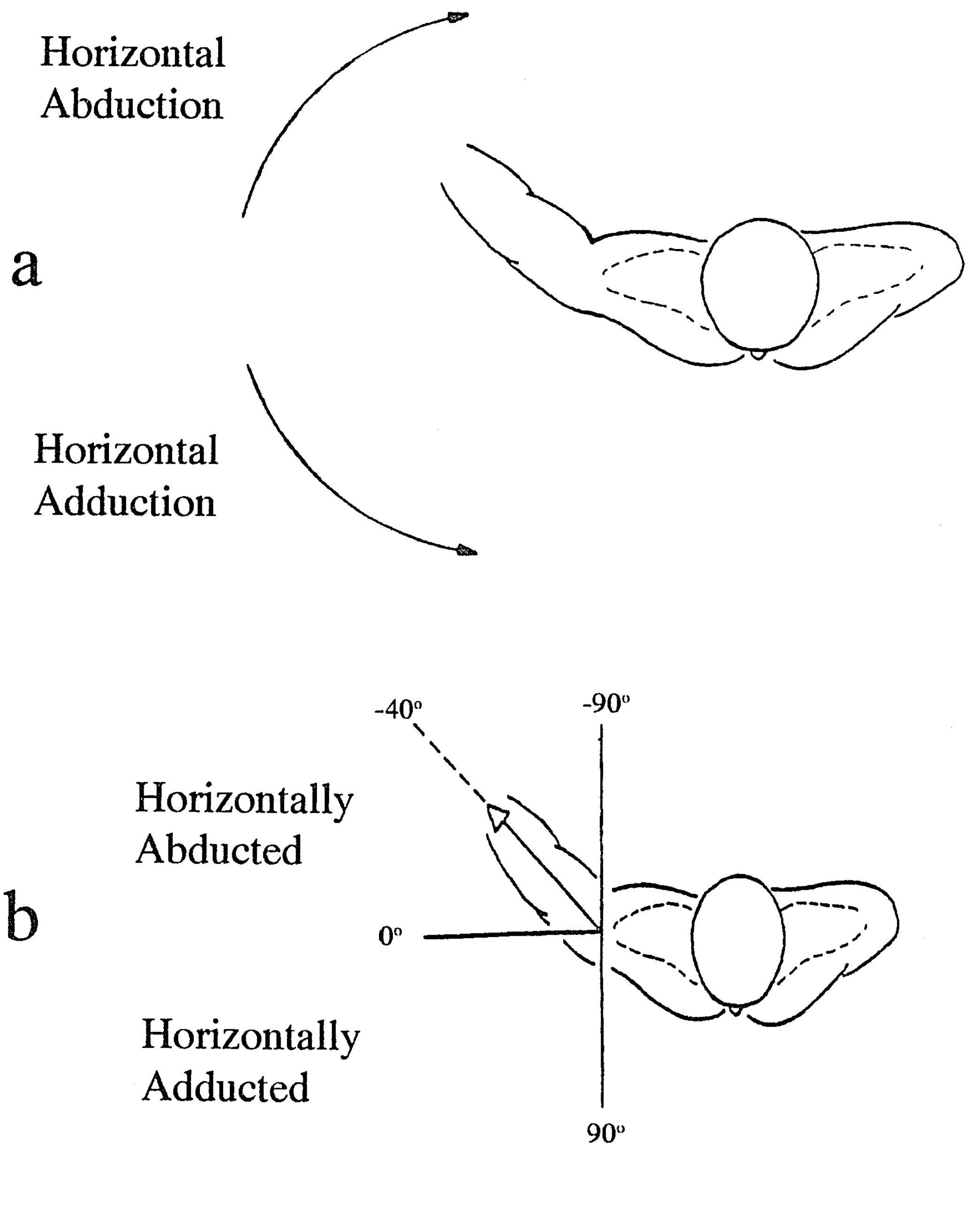


Figure 4. (a) Horizontally abducted/adducted positions (Feltner, 1987), and (b) horizontal abduction/adduction of the upper arm at the shoulder joint (Feltner, 1987).

Horizontally adducted position at the shoulder joint. "Any position of the upper arm where the elbow joint was anterior to the frontal plane of the body" (Feltner, 1987, p. 12) (See Figure 4b).

Internal rotation at the shoulder joint. "A rotation about the longitudinal axis of the upper arm that makes the arm move forward when the elbow joint is in a flexed position" (Feltner, 1987, p. 12) (See Figure 3b).

Internally rotated position at the shoulder joint.

Any position of the upper arm where, if the upper arm was placed in the position of 0° abduction/adduction and 0° horizontal abduction/adduction with the elbow joint flexed, the wrist joint was anterior to the frontal plane of the body (as viewed from the side) (Feltner, 1987, p. 12) (See Figure 3a).

Kinematics. "The description of the movements of segments of the body in space without regard to the forces and moments that caused the movement to occur." (Cavanagh, 1990, p. 548).

Overarm throwing motion/movement. A throwing pattern in which the trunk laterally flexes away from the arm projecting the ball. (Atwater, 1979).

Limitations

This study will be limited by the following factors:

1. The clarity or resolution displayed on the TV monitor by the Peak System, which is standard VHS format (not S-VHS) when digitizing.
2. The clarity or resolution produced by a 60 fields per second video camera.
3. The different experience levels of the subjects.
4. A stationary target.
5. Only throws from the straight drop-back method of passing were analyzed.
6. Defensive personnel were not included.

7. Subjects were not randomly selected.

Delimitations

1. This study was restricted to the kinematic factors involved with throwing the football.
2. The dropback technique used in this study was a 5-step throw on time (no hitch step).
3. The four subjects who participated were right-handed Division I-A quarterbacks.
4. One depth of 12 yards, 10.97 meters, (the length of the actual throw was 24.76 yards, 22.64 meters) was selected for this study.

Hypothesis

Based on previous research this study hypothesized that there is no relationship between lateral stride foot placement and throwing accuracy. In addition, the relationship between and among recorded kinematic variables and throwing efficiency were examined.

Significance

This research provides a qualitative and quantitative description of the football throw that will assist in the evaluation of quarterbacks' throwing mechanics with specific attention to stride foot placement and its effect on accuracy and the center of mass (COM). Until this time there has been scant information available for refining the technique of throwing a football. Out of the 28 starting quarterbacks in the National Football League (NFL), there is no noticeable similarity in throwing styles. Some players utilize an overarm motion (lateral flexion of the spine away from the throwing arm), others use more of a sidearm motion (little or no lateral flexion of the spine to or away from the throwing arm), while others exhibit a full baseball type wind-up motion. Refining overarm throwing techniques to make the pattern more efficient can be made by comparing the various overarm throwing skills with such throwing models as the Kinetic Link System as well as with each other (Kreigbaum & Barthels, 1990).

Finally, this research will provide a protocol for future studies that could attempt to measure and study other types of throws commonly used in football. Examples of other throws are a dropback with a hitch step, throwing while rolling out to the frontside or backside, and awkward throws created by the changing environment (i.e., unanticipated movement by defensive linemen).

Purpose of the Study

This study will report and describe the relationship between and among the kinematic variables involved with throwing a football. A qualitative and quantitative description are presented. Variables that demonstrate a relationship to greater throwing accuracy are discussed.

Based on Schmidt's schema theory, which is a rule, concept, or relationship formed from experience, this research should provide insight into creating a more comprehensive model for quarterbacks, as well as to assist quarterbacks in throwing from a standing position, rolling out of the pocket and throwing on the move, or throwing while evading a defender.

CHAPTER II

Review of Related Literature

This chapter presents the literature related to the kinematic parameters of the entire body during the general throwing motion, the kinetic parameters associated with the throwing arm during baseball pitching, and kinematic parameters and applied physics principles during the specific activity of throwing the football. For organizational purposes this chapter is divided into the following six subtopics: (1) the concentration on injuries to the throwing arm, (2) description of the general throwing motion, (3) the open kinetic link system and its components, (4) studies related to the kinetic parameters during the throwing motion, (5) studies or investigations into the specific skill of throwing a football, and (6) summary.

Introduction

The research literature on the throwing motion has concentrated on two areas. The cause and effect relationship of injuries to the throwing arm, and biomechanical analysis of the kinetic and kinematic parameters responsible for the throwing motion. Since injury issues are beyond the scope of this investigation, the injury review section does not attempt to include a comprehensive discussion of all studies related to throwing arm injuries. Four phases have been defined in order to describe and analyze the overarm throwing pattern: wind-up (I); cocking (II); acceleration (III); follow-through (IV) (Hinkle, 1979; Jobe, Tibone, Perry, & Moynes, 1983, 1984; Pappas, Zawacki, & Sullivan, 1985; Sisto, Jobe, Moynes, & Antonelli, 1987; Yessis, 1984). The four phases occur within approximately a 255 degree range of motion, but according to Pappas et al. (1985) "the entire excursion is not located entirely within the glenohumeral joint" (p. 221). He stated that the movement of the arm occurs through composite actions of the glenohumeral and scapulothoracic joints, in conjunction with trunk extension, flexion, and rotation.

Pappas et al. (1985) suggested that the data collected in throwing studies were influenced by skill level. These studies did, however, create an illustration of the throwing pattern. The literature review will progress from most distal (the ball/hand) to the most proximal (the feet). The descriptions that follow refer to a right-handed thrower. References to forward or backward movements are relative to the direction of the throw (i.e., a movement in the same direction as the throw would be forward, while a movement opposite the direction of the throw would be backward). References to clockwise and counterclockwise rotations are in reference to an overhead view.

The Concentration on Injuries

Most of the research concerning the throwing pattern of adults, "has been primarily evaluated to determine the etiology of injuries" (Montour, 1979, p. 20). Research by Atwater (1979), Kreighbaum and Barthels (1990), and Pedegana, Elsner, Roberts, Lang, and Farewell (1982) contended that using this data as a basis of studying the throwing of a football was difficult because the objects thrown were baseballs or softballs. The research did, however, furnish meaningful information in the areas of effective training regimens for injury prevention, efficient methods of injury rehabilitation, determination of the activation level of the muscles involved, and the determination of the importance of genetic and environmental factors in throwing ability.

Atwater (1979) and Montour (1979) suggested that poor mechanics could cause injuries to the throwing arm. More recently Hang (1981) investigated 112 little league players who participated in a national championship tournament in Taiwan and Sisto, Jobe, Moynes, and Antonelli (1987) studied 8 male collegiate pitchers with electromyographic equipment and high speed cameras operating at 450 frames per second. Both studies suggested that the number or amount of pitches thrown, not the type of pitch thrown, could be the cause of injury to the throwing arm.

Description of the General Throwing Motion

The quarterback, having completed the dropback and side facing to the target, starts the throwing motion with both hands on the ball at or just below chest level. The right foot is planted and supports the weight of the body while the left foot is non weight bearing and underneath or slightly in front of the left hip depending on dropback technique. Initiation of movement occurs when the left foot (stride leg) begins to move forward and may or may not be simultaneous with the separation of the hands (Verduzco, 1991).

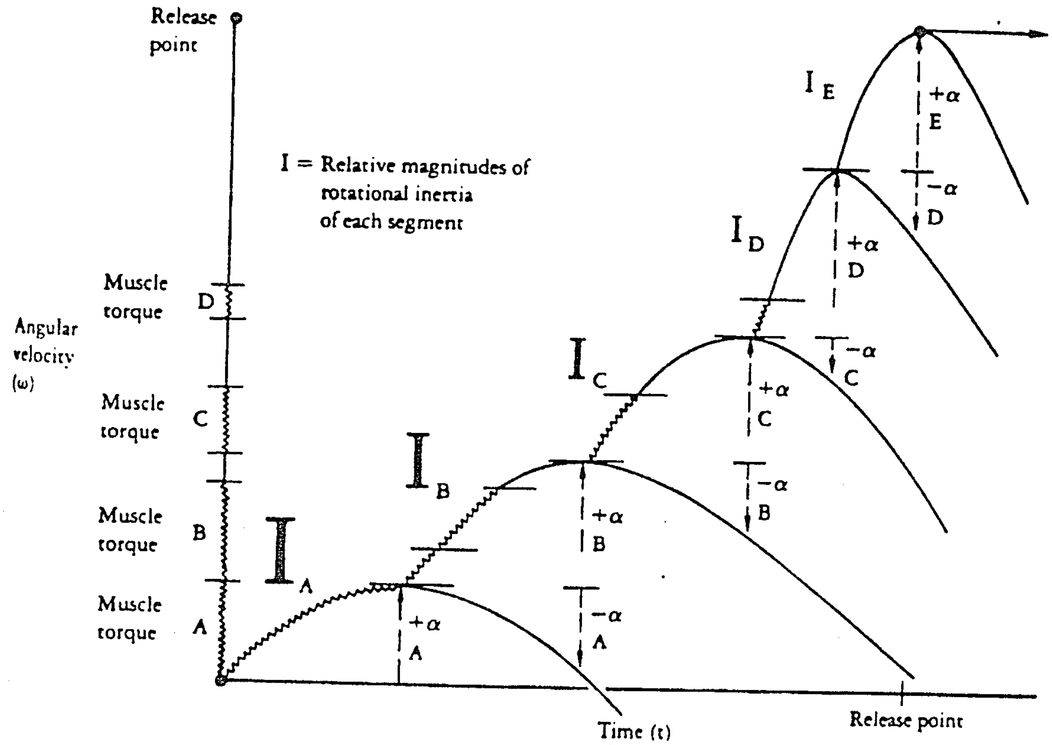
The right hip abducts allowing the stride leg to begin it's forward movement and then blends into extension which initiates the counterclockwise rotation of the pelvis. Toyoshima, Hoshikawa, Miyashita, and Oguri (1974) studied the contribution of the body parts to throwing rubber balls 7cm in diameter. They found that the oppositional step and body rotation accounted for 46.9% of ball velocity, while the remaining 53.1% was produced by the throwing arm. The researchers used seven male subjects who threw 25 times in five different patterns; overhand with a step, overhand without a step, overhand with lower body immobilized, overhand with upper body immobilized, overhand with the upper arm immobilized. The throwing arm, in a position of slight internal rotation and elbow joint flexion, is abducted. The throwing arm continues to abduct as the arm begins to horizontally abduct and externally rotate. Meantime, the stride foot contacts the ground off-line to the left of the midpoint between the right foot of the thrower and the center of the target (Atwater, 1970, 1979; Feltner & Dapena, 1986; Hay, 1985; Yessis, 1984).

The arm, in a position approximately 90° of abduction and 0° of horizontal abduction/adduction, externally rotates to near -90° near the moment of stride foot contact. As counterclockwise pelvis rotation continues, the trunk and shoulders also begin counterclockwise rotation. As a result the most distal segments, the throwing arm and the ball, are left lagging behind (Atwater, 1970, 1979; Feltner & Dapena, 1986; Hay, 1985; Yessis, 1984).

The upper trunk and shoulders continue rotating, but are decelerating, as pelvic rotation has stopped. The counterclockwise rotation of the shoulders initiates rapid elbow extension and the external rotation of the throwing arm reaches its maximal position which is followed immediately by internal rotation. Toyoshima et al. (1974) suggested that the quick acceleration of the throwing arm (and rapid elbow extension) was due to the neuromuscluar system, not conscious muscle contraction. Just before release elbow extension and internal rotation of the throwing arm are combined with radioulnar pronation and wrist flexion. Collins (1960) studied two highly skilled throwers, one male and one female who were marked for digitizing with belts and bands and were verbally instructed to throw sidearm and overarm. Two cameras operating at 64 frames per second were positioned in front and to the side of the subjects. This research conflicted with Atwater (1970, 1979) in terms of the significance of wrist flexion on throwing velocity. Atwater (1970) explored the 3D kinematic aspects of the overarm throw by studying five skilled males, five skilled females, and five average females. Skill level was defined by velocity at release. Three cameras, operating at 64 frames per second were located to the side, rear, and overhead of the subjects. One trial for each subject was used for analysis. Collins found wrist flexion to be a significant factor in throwing velocity, where Atwater did not. Additionally Greenisen, Gross, Madhill, and Marshall (1973) suggested that deviations in hand position were due to radioulnar pronation and not wrist flexion. The follow through, occuring immediately after the release of the ball, consists of continued arm swing in front and across the body elevation of the right, or plant, foot (Atwater, 1970, 1979; Feltner and Dapena, 1986; Hay, 1985; Yessis, 1984).

The Open Kinetic Link System

The open kinetic link system suggests that changes in various joint angles are not abrupt, more correctly, they gain velocity in a smooth sequential manner. In fact, the shoulder and throwing arm act in a wheel-axle arrangement. This supports the research conducted by Feltner (1987) when he concluded the rapid elbow extension was not due to the activation of the elbow extension muscles; rather it was largely the product of hip, trunk, and shoulder rotations. Kreighbaum and Barthels (1990) stated "The (five times) greater acceleration in the wheel-axle system gives this system two and one half times the linear velocity of the lever system, although the lever system has a larger radius of rotation" (p. 614). This characteristic could account for the conflicting research about the relationship between strength and throwing velocity. Toyoshima et al. (1974) and Boucher and Flieger (1983) found strength to have a strong relationship to throwing velocity while Jobe et al. (1983, 1984) and Sisto et al. (1987) found muscles not activated at a intensity level commensurate with the velocity of the changing joint angles. Figure 5, a conceptual model of the kinetic link principle, theoretically shows the low muscle activation level of the arm as it medially rotates about the longitudinal axis of the shoulders (muscle torque D). Verduzco (1991) explained the sequential rotations of the kinetic link system this way, "as each segment proximal to the axis of rotation accelerates, the succeeding distal segment will be initially left behind; as the proximal segment decelerates the succeeding distal segment acquires the speed of the preceding proximal segment" (p. 24). The following segments (the hand/ball, the lag-back characteristic of the arm, sequential rotations of the hips, trunk, and shoulders, and the stride leg) are components of the open kinetic link system except for lateral deviation of the spine.



Muscle Torque A = the trunk rotating about the vertebral axis
Muscle Torque B = the shoulder girdle rotating about the sternoclavicular axis
Muscle Torque C = the arm rotating about the shoulder axis
Muscle Torque D = the forearm extending about the elbow axis

****Note:** The muscle torque of the pelvis has been omitted so that the skill will fit the model.

Firgure 5. Example of correctly sequenced rotations and the relatively small muscle torque of the tricep muscle. Kreighbraum and Barthels (1990). (Used by permission).

The Influence of Ball Mass on Throwing. As might be expected the following two studies found that throwing velocity decreases with significant increases in ball mass. Kunz (1974) investigated 20 subjects which were divided into two groups, good throwers and poor throwers. The path and velocity of the hand and the hips were measured with rubber band gonimeters as the subjects threw same size rubber balls ranging from 0g to 800g in mass. Toyoshima and Miyashita (1973) studied seven adults and six boys who threw rubber balls (70mm in diameter) of weights from 60g to 500g. Data from the fastest throws were used for analysis. Bowne (1956) reported that the difference in mass between a baseball and softball was not significant enough to produce a decrease in performance. Atwater (1979) reported the mass of a football to be 415g, which according to the aforementioned research will produce decreased release velocity, in and of itself, even though all other parameters may be held constant.

The "Lag-Back" Characteristic of the Arm. To understand this characteristic of the throwing motion, it might be helpful to differentiate between two possible reference frames: (1) the throwing arm in reference to the body, and (2) the arm and body, as a whole, in reference to the ground and background.

Atwater (1970) observed the displacement of the hand/ball before release and found that the primary movements of the ball were forward, vertical, and lateral. As an athlete breaks his/her hands to initiate the throwing action the hand/ball appears to be going backward when focusing exclusively on the body. A more complete perspective would be to view the surrounding environment (the ground and background). This perspective helps to demonstrate that while the arm is extending and horizontally abducting (apparently backward) the body as a whole is moving forward toward the target resulting in little or no actual backward movement of the hand/ball. Essentially the hand/ball is "lagging back" not moving in the backward direction.

Kreighbaum and Barthels (1990) listed the "lag-back" characteristic as the first of four components in their Kinetic Link System. "The segment-object 'lags-back' as the proximal segments 'move out from under' the distal segment, and eventually the distal end will catch up to the proximal segments at release" (p. 616). The "lag-back" characteristic has also been termed inertial lag (Feltner, 1984, 1987; Feltner & Dapena, 1986; Kreighbaum & Barthels, 1990). Kreighbaum and Barthels (1990) also stated that

> the "lagging-back" of the arm and hand segment remains until one or more of the following occurs: (1) the acceleration of the proximal segment decreases or ceases, (2) the elastic or structural limit of a joint's ROM is reached, or (3) the stretch reflex is activated (p. 605).

Michaud (1990), in his overview of the unilateral overarm throw, reported that "the entire arm lags behind the shoulder line and is forced by inertial forces and the pull of the posterior glenohumeral musculature into a position of extreme external rotation" (p. 15). He also mentioned that it has been theorized that an increased range of external rotation provides the muscles responsible for internally rotating the humerus a longer range of motion and, therefore, a longer period of time to apply force.

Sequential Segmental Rotations of Hips, Trunk, and Shoulders. Atwater (1970) observed that the sequence in which the segments reached their peak angular velocity in skilled throwers was the pelvis, upper trunk, and upper arm (as a whole); while unskilled throwers tended to move the entire trunk and arm forward as a unit. Moving the segments simultaneously resembles a push-like pattern and could also be described developmentally as a more immature pattern.

Kreighbaum and Barthels (1990) reported the second characteristic of their kinetic link model as segmental rotations occurring sequentially (as opposed to simultaneously in a pushlike pattern) to produce high velocity. The pattern of these rotations follows an initial rotation in the base segment, the most stable part of the system, with subsequent forward rotations of the next distal segment. Each of the subsequent segments rotates forward as the previous segment has achieved its greatest angular velocity. This procedure continues from proximal to distal, until the last segment (the hand/ball) comes forward.

For a model of the kinetic link system which illustrates correctly sequenced rotations and the degree to which muscles are activated presented by Kreighbaum and Barthels (1990) see Figure 5. Failure to accelerate each successive segment, or link, when the preceding segment reaches peak acceleration results in a velocity less than maximum.

The Stride Leg. Tracings from Atwater's (1970) study show that subjects placed their stride foot directly on the midline between their bodies and the target (see Figure 6a). This on-line placement of the stride foot on the midline alters the balance of throwers and may cause the center of mass (COM) to have an arched path off the midline between the back foot and the target (Verduzco, 1991).

Hay (1985), stated that an off-line stride permits more complete frontal rotation of the hips. Additionally, he stated in his description of a pitcher's foot work,

> this movement is assisted by a simultaneous forward sweeping of the stride leg, which carries the striding foot across in front of his body to land to one side of an imaginary line joining the midpoint of home plate to the midpoint of the pitching rubber (p. 194) (see Figure 6b).

Lateral Deviation of the Spine. Although not directly a component of the open kinetic link system lateral deviation of the spine is part of the throwing motion. Lindner (1971) presented illustrations of subjects performing different overarm throws and concluded that the upper part of the body laterally deviates away from the throwing arm during the overarm pattern (see Figure 7a). Lindner (1971) added, "since this phenomenon

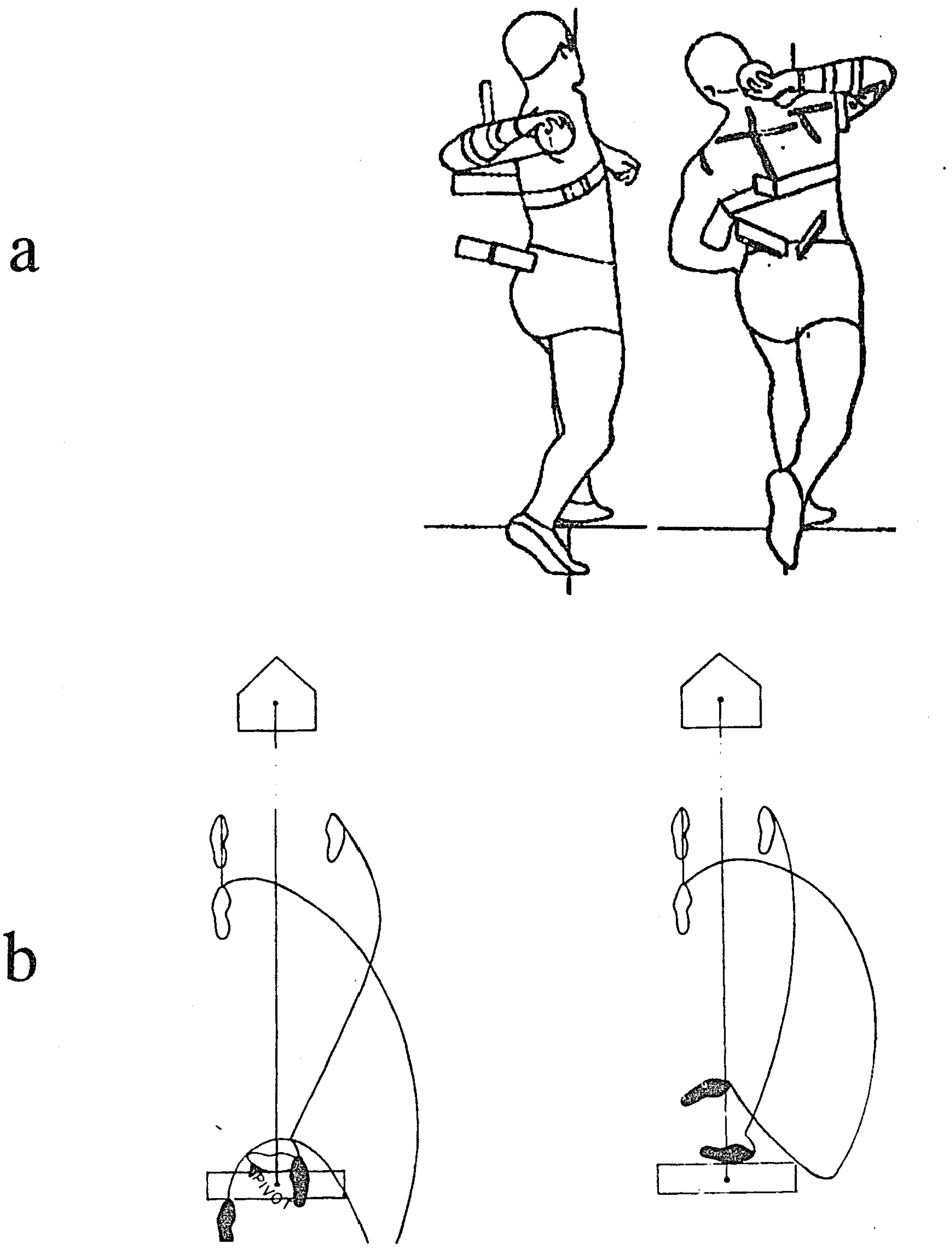
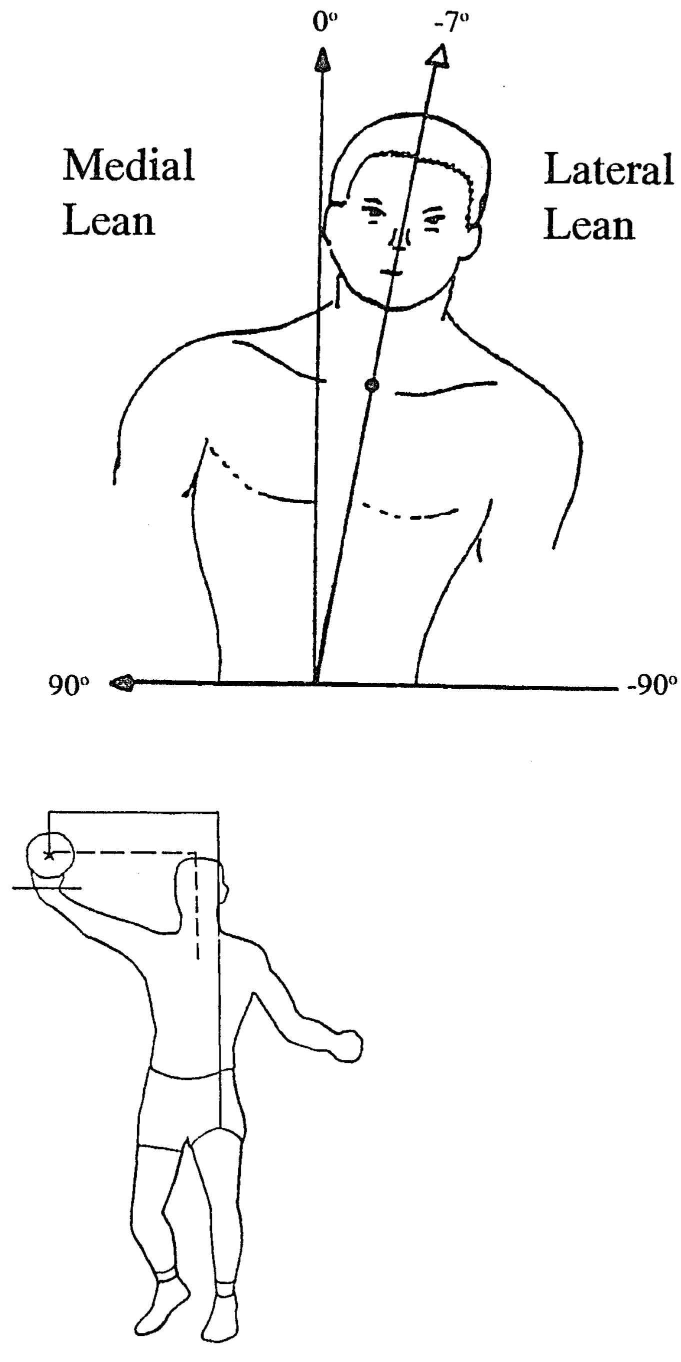


Figure 6. (a) Stride foot placement directly on the midline between the body and the target (Atwater, 1970) (Used by permission), and (b) off-line placement of the stride foot (Hay, 1985) (Used by permission).

a



b

Figure 7. (a) Example of lateral deviation of the spine (Feltner, 1987), and (b) an example of no lateral deviation of the spine (Cooper and Glassow, 1972) (Used by permission).

has been observed not only in trained experts but also in children, it must be considered a natural movement" (p. 245).

Adrian and Cooper (1989) reported that during an underarm pattern, "If the trunk is flexed to the right, the moment arm will be lengthened; if the trunk is flexed to the left, the moment arm will be shortened" (p. 498). The principle of a moment arm may also be applied inversely to the overarm pattern. When the trunk laterally flexes to the left, or away from the throwing arm, the moment arm is longer than when there is no lateral flexion or if the trunk is flexed to the right (see Figure 7 b).

Studies Related to the Kinetic Parameters during the Throwing Motion

Research concerned with the kinetic parameters of throwing have concentrated on the throwing arm, specifically the shoulder and elbow. The validity of the results of some studies has been questioned by Feltner (1987), but all will be presented here.

Gainor, Piotrowski, Pugl, Allen, and Hagen (1980) were the first to report the kinetic aspects of throwing. The investigators filmed several baseball pitchers two-dimensionally, one camera placed laterally and one placed posteriorly. The authors found very small (near zero) internal/external rotation torques exerted on the arm until about 160 ms before release, when an external force was exerted. This external rotation torque reached 1700 Nm, its greatest value, at the moment of maximum external rotation. An internal rotation torque followed, with a maximum value of 1600 Nm, while the arm was internally rotating. This internal rotation torque existed until 20 ms after release, when an external rotation torque (maximum value, 1700 Nm) was again exerted on the arm by the trunk.

Feltner (1987) questioned the relevance and validity of the torque data reported by Gainor et al. (1980) for these reasons:

1) Because the subjects in the study did not try to maximize ball speed, the kinematic data were significantly different from studies whose subjects performed at maximum levels (Feltner, 1984; Feltner & Dapena, 1986; Pappas et al., 1985).

2) The reported external rotation torque values seemed to be incorrect. Before maximum external rotation, the arm would possess an angular velocity which would decrease to zero when maximum external rotation occurred. For this sequence to occur, an internal rotation torque would have to be exerted prior to and at maximum external rotation, not the external torque Gainor et al. (1980) reported.

In 1984 Horn computed shoulder and elbow kinetics on a single major league pitcher, who did not attempt to maximize the speed of the pitch. The data reported by Horn, a maximum velocity of 22 m/s and a velocity at release of 5 m/s, are considerably lower than velocity at release (33.5 m/s to 39.0 m/s) reported by (Atwater, 1970; Feltner, 1984; Feltner & Dapena, 1986; Sakaris, 1978; Selin, 1959; Tarbell, 1971; Vaughn, 1985). Horn (1984) acknowledged problems with procedures used in his study for coordinate data optimization, smoothing, and differentiation that led to large fluctuations in joint force and joint torque data.

Feltner (1984) reported shoulder and elbow forces and torques for fastball pitches of collegiate pitchers, but the accuracy of these data is questionable because of a problem Feltner identified. The uniforms the pitchers wore obscured the location of the shoulder and elbow landmarks.

Feltner and Dapena (1986) investigated the dynamics of the shoulder and elbow joints in eight intercollegiate varsity baseball pitchers. The subjects were filmed 3-dimensionally during a team practice throwing fastball pitches with maximum effort. The authors reported small joint torques at the shoulder until near the instant of stride foot contact. Also at stride foot contact, a horizontal adduction torque (maximum value, 110 Nm) was present at the shoulder joint.

Feltner (1987) studied 8 male collegiate pitchers. The subjects were filmed 3-dimensionally. Direct linear translation (DLT) was used in the analysis of one trial for each subject. Feltner (1987) concluded "The rapid elbow extension that occurred prior to ball release was due primarily to the counterclockwise trunk rotation that occurred during the pitch, and not to the activity of the elbow extension muscles" (p. 2). He continued to report that the extreme external rotation of the arm was largely the product of sequential actions of horizontal adductor muscles and abductor muscles of the shoulder.

Studies or Investigations into the Specific Skill of Throwing the Football

The review of literature in this section progresses from general physics principles applied to throwing the football to detailed investigations on passing the football. Studies concerned with different types of throws (roll-out pass and jump pass) will also be included.

Hinkle (1979) discussed the application of several principles of physics and throwing the football. The first three of the four presented here appear to be flawed. First, he seems to have made an error when he described the placement of the stride foot,

> this step has to be directly toward the receiver ... If the thrower steps to either side of the line of center from the quarterback to the receiver, his timing, accuracy, and continuous motion will be lacking. A step which is 'out of alignment' will not permit the full rotation movement of the hip (p. 15).

Secondly, in his discussion of the law of acceleration, Hinkle (1979) alleged that to gain maximum acceleration, all the body segments; stride foot, chest, left arm, and throwing arm should move forward simultaneously. A more correct and precise view should note that while the individual segments are moving forward, vertically, and laterally as Atwater

(1970) reported, the body as a whole is moving forward. Thirdly, Hinkle (1979) stated that the reason the throwing arm reacts in a "whip-like" fashion is because the arm is in a "cocked" or flexed position as the stride foot moves forward. A more precise explanation of this phenomenon was presented earlier by Kreighbaum and Barthels (1990). The arm "lags back" because the proximal segments have "moved out from under" the distal segments. Lastly, Hinkle (1979) reported that after release the wrist rotates forward and down (into flexion and pronation).

Atwater (1979) suggested "that the size and weight (415g) of a football cause the passer to keep his hand behind the ball, which possibly restricts the range of preparatory actions" (p. 56). This statement would seem to emphasize the importance of maximizing the efficiency of the segments involved in throwing that occur prior to the arm coming forward.

Yessis (1984) reported on the actions that occur when throwing the football and the muscles responsible for these actions. He stated "When the pelvic girdle maximally decelerates to stop in the front facing position, which produces the longest force arm, the shoulder girdle begins rotating" (p. 6). If the movement of the shoulders occurs when the trunk reaches maximum acceleration then that statement complies with the previously mentioned research (Atwater, 1970; Kreighbaum & Barthels, 1990; Michaud, 1990; Moorehouse & Cooper, 1950). However, if shoulder rotation starts when hip rotation has stopped then this statement is flawed. Yessis (1984) also reported that during shoulder rotation the forearm usually externally rotates to a position parallel to the ground. Additionally, elbow extension occurs as medial shoulder rotation takes place, not to create additional force, but rather to gain a higher release point. Yessis (1984) continued, when the forearm approaches a position perpendicular to the ground, "wrist flexion and hand pronation (which is an effect of elbow extension after release) occur" (p. 8). Yessis

(1984) also stated the release is concluded 6 to 8 inches in front of the lateral plane of the body. Yessis (1984) stated "The timing of each action is very precise so that the next sequential action begins acceleration when the preceding action is undergoing deceleration" (p. 71). This is not consistent with previously reported literature (Kreighbaum & Barthels, 1990; Moorehouse & Cooper, 1950) and questions on this issue were raised earlier in this section. Lastly, Yessis added that when the shoulders rotate maximally to 90^{o} degrees or more this may provide over 50% of the total force generated.

Carlson (1962) used game film to descriptively analyze four right-handed college quarterbacks from the northwest: Washington State University (3) and the University of Oregon (1). The feet, hips, shoulders, grip, release, posture, carriage of the arm, and body balance were the focal points of the study. The following characteristics were observed during a straight dropback, roll-out, and jump passing: (1) the lead, or left foot, was the focal point for determining the direction of the throw; (2) weight transfered from the right foot, which served as a base, to the left foot; (3) the right hip led the right shoulder; (4) the shoulders were perpendicular to the target and provided a base for the throwing arm.

Mikszewski (1968) compared the accuracy of roll-out passes to the right with the accuracy of roll-out passes to the left, at three distances: 6, 12, and 25 yards. Six Springfield College quarterback candidates were the subjects used. Mikszewski (1968) made the following conclusion: right-handed quarterbacks were significantly ($\underline{p} < .01$) more accurate throwing to their right; the accuracy of their passes decreased as the distance of the pass increased; and there was no significant difference in accuracy to the right or left at the 12 and 25 yard distances.

Verduzco (1991) in his study of one quarterback identified the following phases: stance (I); initiation of movement (II); acceleration (III); release/control (IV); follow through (V). He reported that the stride, or left foot should be placed approximately 12 inches to the left of the midline between the quarterback and the receiver. This off-line placement provides a new base of support and rotary stability. He also stated that the toe should be pointed slightly in toward the midline while the heel is pointed slightly out away from the midline. The distance of the stride was reported to be between 12 and 24 inches depending on the distance of the throw. At the moment of stride foot contact, the stride leg is flexed 70-75°. He described the sequential rotations of the hips, torso, and shoulders, the position of the forearm (perpendicular to the ground) due to extreme external rotation of the humerus, and that the backward motion of the hand/ball should stay on the same horizontal level from which it began but did not give quantitative data to accompany the descriptions.

During the acceleration phase the left knee extends from 130° to nearly 180° at release, the right hip "lags behind" the left hip by 5-10°. Additionally, at the end of this phase the right elbow extended from 80-90° to 175°.

During the release/control phase the left knee is nearly fully extended at approximately 175° and the right knee which, at the the start of the acceleration phase was extend to 175°, is flexed to 140° at release. The hips, torso, and shoulders are in the front facing position, as described by the kinetic link system (Kreighbaum & Barthels, 1990). The right elbow is extended to 170° at release and the radius and ulna impart 45° of radioulnar pronation.

The follow-through phase accounts for nearly half of the entire throwing motion, 105° of the previously reported 255° . The right foot should travel forward approximately equal to the position of the left foot. The right knee is at 145° of flexion and the hips, torso, and shoulders are in the front facing position in the direction of the target. The elbows extend to 150° at the point of maximum deceleration and the radius and ulna have completed radioulnar pronation.

Summary

The kinematic data on the general throwing motion, along with that reported on most specific variations such as pitching, have been accurately and thoroughly investigated (Atwater, 1970, 1979; Bowne, 1956; Kunz, 1974; Lindner, 1971; Michaud, 1990; Toyoshima et al., 1974, 1981). In comparison the kinetic data have been inconsistent and invalid (Feltner, 1984; Gainor et al., 1980; Horn, 1984). Recent investigations have produced more meaningful cause-effect information about the two link kinetic chain of the throwing arm (Feltner, 1987; Feltner & Dapena, 1986). Carlson (1962), Mikszewski (1968), Verduzco (1991), and Yessis (1984) have provided the most detailed information about the specific skill of throwing the football.

CHAPTER III

Methodology

This chapter will describe the procedures that were used to collect, analyze, and report the kinematic data collected during a football throw. This chapter is divided into the following sections: (1) general procedures, (2) cinematographic techniques, (3) video analysis, (4) data collection, (5) kinematic analysis, and (6) statistical procedures.

General Procedures

The presentation of the general procedures that were used in this study are categorized as follows: (1) selection of subjects, (2) videotaping procedures, (3) the target, (4) subject markings, and (5) selection of trials for analysis.

Selection of Subjects

Subjects used in this study were one former and three present division I-A quarterbacks. The former division I-A quarterback was from Yale University and played during the 1987-1990 seasons, and the present division I-A quarterbacks were from San Jose State University. All athletes were right handed. Approval by the Human Subjects Institutional Review Board at San Jose State University was obtained prior to data collection (Appendix A). Consent was obtained prior to data collection as well (Appendix B). At the time of the videotaping session all subjects were healthy and injury free.

Videotaping Procedures

The subjects were videotaped during January and February, 1992 at the San Jose State University football practice field. Each quarterback threw five trials at a designated target placed at a position equivalent to that at which a receiver would be if running a standard 12 yard curl pattern. When a trial(s) did not hit any part of the target an additional trial(s) was/were given. The total number of trials was recorded. The depth (displacement) of the target was 12 yards (10.97 meters) vertically from the line of scrimmage and 17 yards

(15.54 meters) laterally from the quarterback (M. Verduzco, personal communication, October 30, 1991). The subjects took a normal five step dropback and threw to the target, without taking a hitch step (see Appendix C). According to Schnellenberger (1984) and Walsh (1978, 1981) the depth on a quarterback's 5-step drop should be five to seven yards (see appendix B). Therefore, the center of the calibration frame was set at a depth of six yards (5.49 meters). The distance of the actual throw was 24.76 yards (22.64 meters). Each subject was allowed to practice, in his usual manner, until he felt able to perform the skill properly (Mikszewski, 1968).

The Target

The target was a modified version of the target Mikszewski (1968) used in his study on the accuracy of roll-out passing. The target was housed within a rectangular frame made of two inch by four inch boards. The area within the frame was a solid piece of plywood painted black. The square zones inside the frame were divided by white painted lines. The center square was given the highest point value and each concentric square zone toward the edge of the target was given lower point values (see Appendix D). An assistant was assigned to mark the trial number on the target so that the most accurate trial could be identified.

Subject Markings

The subjects were videotaped without shirts, wearing lycra type shorts, below ankle length socks, and shoes. The lycra shorts provided a stable marking surface for the hip area. Flat black water-based paint was used to identify the joint landmarks. Subjects were marked after they had warmed-up. In accordance with the protocol used by Verduzco (1991), black dots, three inches in diameter, marked: (1) proximal phalanx (toe) and calcaneus (heel), marked over the subjects shoes; (2) approximate lateral, anterior, and posterior greater trochanter of the femur (hip), marked over the lycra type shorts; (3)

umbilicus and the approximate corresponding lumbar vertebra (L4 or L5); (4) lateral, anterior, and posterior aspects of the greater tubercle of the humerus (shoulder); (5) suprasternal notch and the approximate corresponding thoracic vertebra (T1 or T2).

In accordance with Feltner and Depena (1986), bands were painted around the following areas: (1) lateral and medial malleolus, and the related posterior and anterior areas of the ankle; (2) the lateral and medial epicondyle of the femur and the patella (knee); (3) lateral and medial epicondyle of the humerus, and the olecranon process of the elbow. Independent dots, one inch in diameter, marked the styloid processes of the radius and the ulna.

Selection of Trials for Analysis

Feltner's (1984) study showed little variation among the pitches of any given pitcher. Therefore, any trial of a given subject should be representative of most throws, of the same type, thrown by that subject. One trial, therefore, was analyzed for each subject. The best throw was used for digitizing in this study. The best throw was defined as the most accurate (closest to the center of the target) throw for each subject.

Cinematographic Techniques

The videotaping techniques for this study are presented in this section. This section is arranged as follows: (1) videotaping equipment, (2) the Peak Performance calibration frame, (3) camera settings, locations, and operation.

Videotaping Equipment

The subjects were videotaped with the Peak Performance 3-D Motion Analysis System. One Panasonic Camcorder, model AG450, and one Panasonic D-5000 video camera were phase-locked. Two professional/industrial quality Sony videotapes were the medium used to record the trials.

Peak Performance Calibration Frame

The Peak Performance calibration frame uses the Cartesian (XYZ) coordinate system. The sphere marked A is the reference sphere for the entire frame, with coordinates (0,0,0). This calibration frame (Appendix E) was videotaped for approximately one minute before the recording of any trials. The calibration frame encompasses an eight foot cube area, which the subjects dropped back into and threw from. The calibration frame defined the object space from which the subjects threw. Direct Linear Transformation (DLT) which was programmed into the Peak Performance System was used to smooth the coordinate data from each camera view when converted into a single picture. The DLT method used was based on investigations by Abdel-Aziz and Karara (1971), Miller, Shapiro, and McLaughlin (1980), and Shapiro (1978).

Camera Settings, Locations, and Operation

Both Panasonic cameras operated at 60 fields per second (fps). Based on Verduzco's (1991) protocol the video cameras were placed on tripods and located as shown in Appendix F. The video cameras were located on the throwing arm side of the subject and were at a ninety degree angle to each other as per the Peak Performance System manual (version 1.7.0, 1990). The AG450 camcorder, the forward camera, was slightly to the left of the actual throw. The D - 5000 video camera was located behind and to the throwing arm side of the subject. The height of the video cameras on the tripod and the distance they were from the subjects was determined in a pilot session the day prior to the actual videotaping session. The height of the cameras was 4 feet 8 inches (1.43m) and they were 75 feet (22.86m) from the throwers. The video cameras were phase-locked to synchronize operation.

Video Analysis

The procedures that were used to analyze the videotaped trials are described in this section. The section is divided as follows: (1) analytic equipment and (2) digitizing the throw.

Analytic Equipment

The Peak Performance 3-D Motion Analysis System is an integrated computer-video work station. The Peak Performance System consists of the following hardware components: computer, video system, calibration frame, and genlock adapter. The software package controls the video cassette recorder (VCR) during digitizing and has a direct linear translation (DLT) method, for data smoothing, built in.

Digitizing the Throw

The front tip of the football and 21 body landmarks were digitized throughout the throwing motion. As stated before, the quarterbacks dropped back and threw. The dropback was not videotaped or digitized as this was beyond the scope of this investigation and was researched in depth by Verduzco (1991). The digitizing process started the instant the fifth step contacted the ground, and continued until completion of the follow-through. Each landmark was digitized in all frames. The digitizing points were (Appendix G):

1. Left Toe (of the shoe)
2. Left Heel (of the shoe)
3. Left Ankle
4. Left Knee
5. Left Hip
6. Umbilicus
7. Suprasternale Notch
8. Left Shoulder
9. Left Elbow
10. Left Wrist
11. Right Ear
12. Forehead
13. Right Shoulder
14. Right Elbow
15. Right Radius
16. Right Ulna
17. Right Hip
18. Right Knee
19. Right Ankle
20. Right Heel
21. Right Toe
22. Center of the ball

Data Collection

The tip of each football was coated with chalk so that it left a mark on the black background of the target. An assistant marked each throw with the trial number. After the five trials of each subject were completed the researcher identified the most accurate throw. The target was wiped cleaned after each subject.

Kinematic Analysis and Statistical Procedures

This section describes the specific measures that were computed. For the purpose of organization this section is divided into two sections: kinematic analysis and statistical procedures.

Kinematic Analysis

To investigate the interactions among the segments in the throwing motion and to aid in the interpretation of the data, the following kinematic parameters were calculated:

1. the displacement of the stride foot when it contacts the ground and the displacement of the COM;
2. the maximum angular velocity and the angular displacement, from stride foot contact to release, of the hips;
3. the amount of lateral deviation and anterior lean of the spine at the moments of stride foot contact and release;
4. the maximum angular velocity, the angular displacement, from stride foot contact to release, and the amount of lag at stride foot contact and release of the shoulders;
5. the angles that define the position of the upper arm at stride foot contact and release (abduction, horizontal abduction/adduction, and internal/external rotation);
6. the angle and velocity of elbow extension at stride foot contact and at release;
7. the velocity of the ball at release;

8. the angle and velocity of stride leg knee extension/flexion at stride foot contact and at release;
9. the linear displacement, in the X (front to back), Y (vertical), and Z (side to side) planes, of the ball.
10. the maximum amount of external rotation of the upper arm and the time at which it occurs in relation to ball release and the maximum internal rotation velocity and the time at which it occurs in relation to ball release

Statistical Procedures

The means and standard deviations were reported for each of the kinematic variables. All kinematic data were calculated on the Peak Performance 3-D Motion Analysis System and a program developed by Greg Rash, Ed.D. Means, standard deviations, and the Pearson Product-Moment Correlation (PPMC) were calculated with the Statview 512+ and Microsoft Excel software programs for the Macintosh. The mean value of the five trials that hit the target for each subject were used in the PPMC to describe the relationship between stride foot deviation (laterally from the midline connecting the arch of the right foot and the center of the target) and accuracy. Stride foot deviations from the mid-line were measured by calculating the perpendicular distance from the X axis. The mean of the five trials was the dependent variable, while the independent variable was stride foot deviation.

CHAPTER IV

Results and Discussion

Employing the procedures in the methods chapter, kinematic data were collected on the most accurate trial thrown by each quarterback. The values used in the accuracy correlation were the average score of the five trials and the distance of the left ankle from the mid-line between the target and thrower. The data are shown in five sections: (1) ball velocity, (2) linear displacements, (3) angular displacements and velocities, (4) trunk orientation, and (5) accuracy correlation. Table 1 describes selected kinematic parameters of the present and other similar studies.

Ball Velocity

In the 340ms before release, the velocity of ball increased, decreased, and then increased again (Figure 8). This oscillation is part of the general throwing motion, representing the "lag-back" characteristic, and was investigated in detail by Atwater (1970). The mean velocity of the ball in this study was 19.85 m/s (44.40mph) (Figure 9). The velocity is close to those reported by Rash and Shapiro (1992) and by Wick, et al. (1991) of 17.43m/s (43.9mph) and 20.56m/s (46mph), respectively.

Linear Displacements

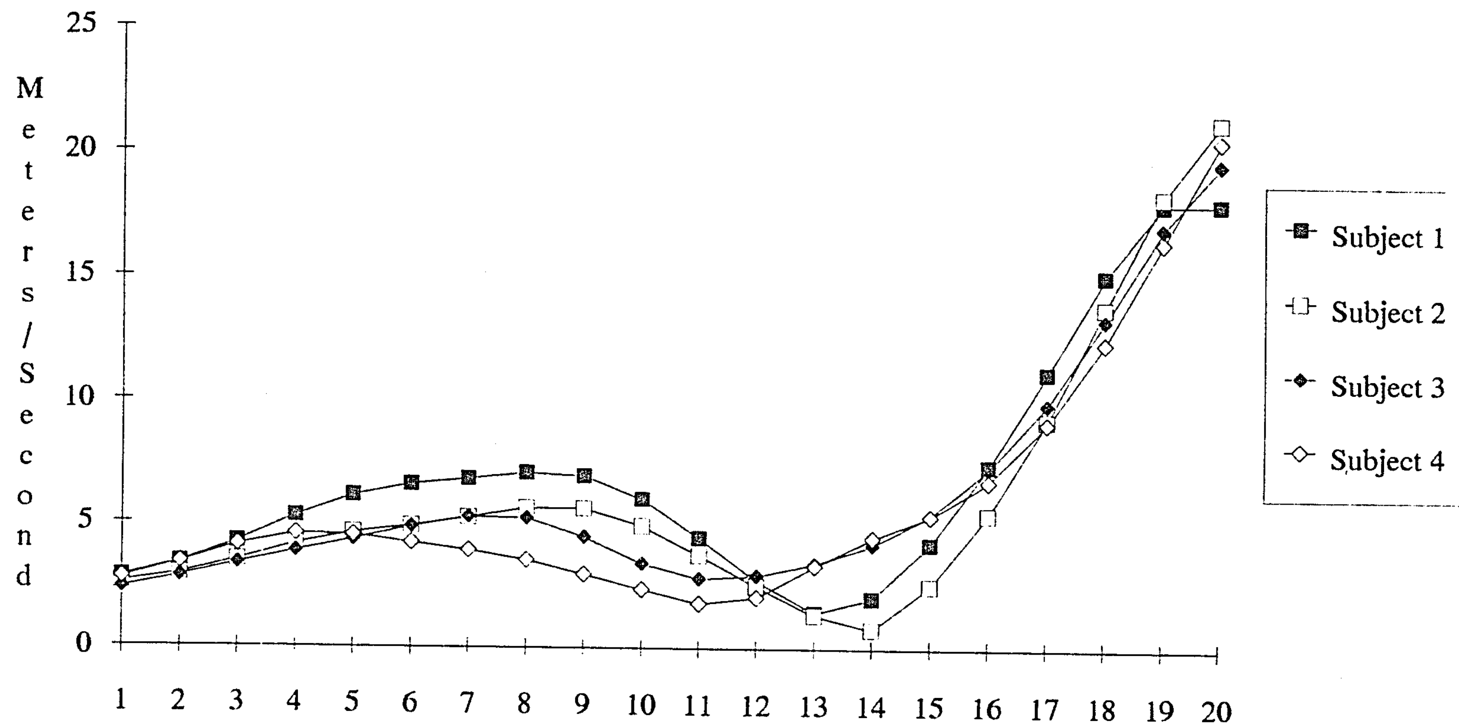
The hand/ball segment undergoes movement in all three planes before it is released. Overhead and side views of ball displacement are presented in Figures 10, 11, 12, and 13. This movement or displacement demonstrates how the hand/ball segment in the Kinetic Link System is left behind as the rest of the body moves out from underneath it and also allows the hand/ball segment to be positioned for acceleration. The distances reported subsequently were calculated from the start of digitization until release. The time to release was 769ms.

Table 1

Means and standard deviations of selected kinematic parameters from previous studies and present study at stride foot contact, delivery phase, and at release.
(All numbers are rounded to nearest whole number).

	HEPPE (n = 4)		WICK (n = 15)		RASH (n = 8)		VERDUZCO (n = 1)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
FOOT CONTACT (°)								
Elbow Angle	86	21	75	13	-	-	-	-
Int./External Rotation	23	30	2	36	-	-	-	-
Shoulder Abduction	0	7	15	17	-	-	-	-
Horizontal Adduction	-20	8	-2	17	-	-	-	-
Lead Knee Angle	132	6	137	11	-	-	70-75	-
DELIVERY PHASE (From SFC to REL)								
Max Ext. Rotation(°)	-84	11	-78	12	-71	15	-	-
Max Elbow Ext Vel.(°/s)	1331	79	1716	193	1111	178	-	-
Max Int. Rot. Vel.(°/s)	1177	132	4586	843	1200	477	-	-
Max Shoulder Vel.(°/s)	771	118	1017	177	-	-	-	-
Max Hip Velocity(°/s)	374	105	518	97	-	-	-	-
RELEASE (°)								
Elbow Angle	131	4	124	28	124	-	170	-
External Rotation	-44	7	-55	25	-41	12	-	-
Shoulder Abduction	8	8	24	15	11	6	-	-
Horizontal Adduction	16	6	21	10	17	8	-	-
Lead Knee Angle	153	6	148	6	-	-	175	-
Internal Rotation (o/s)	1177	132	4586	843	1200	477	-	-
Ball Velocity (m/s)	20	1	21	2	17	-	-	-
OVERALL MAXIMUMS (°/s)								
Internal Rotation Vel.	2790	129	4586	843	2348	662	-	-

Ball Velocity



Field Number.
Release (REL)= 20, Average Stride Foot Contact (ASFC)= 7.

Figure 8. Ball velocity from 340ms before release up to release.

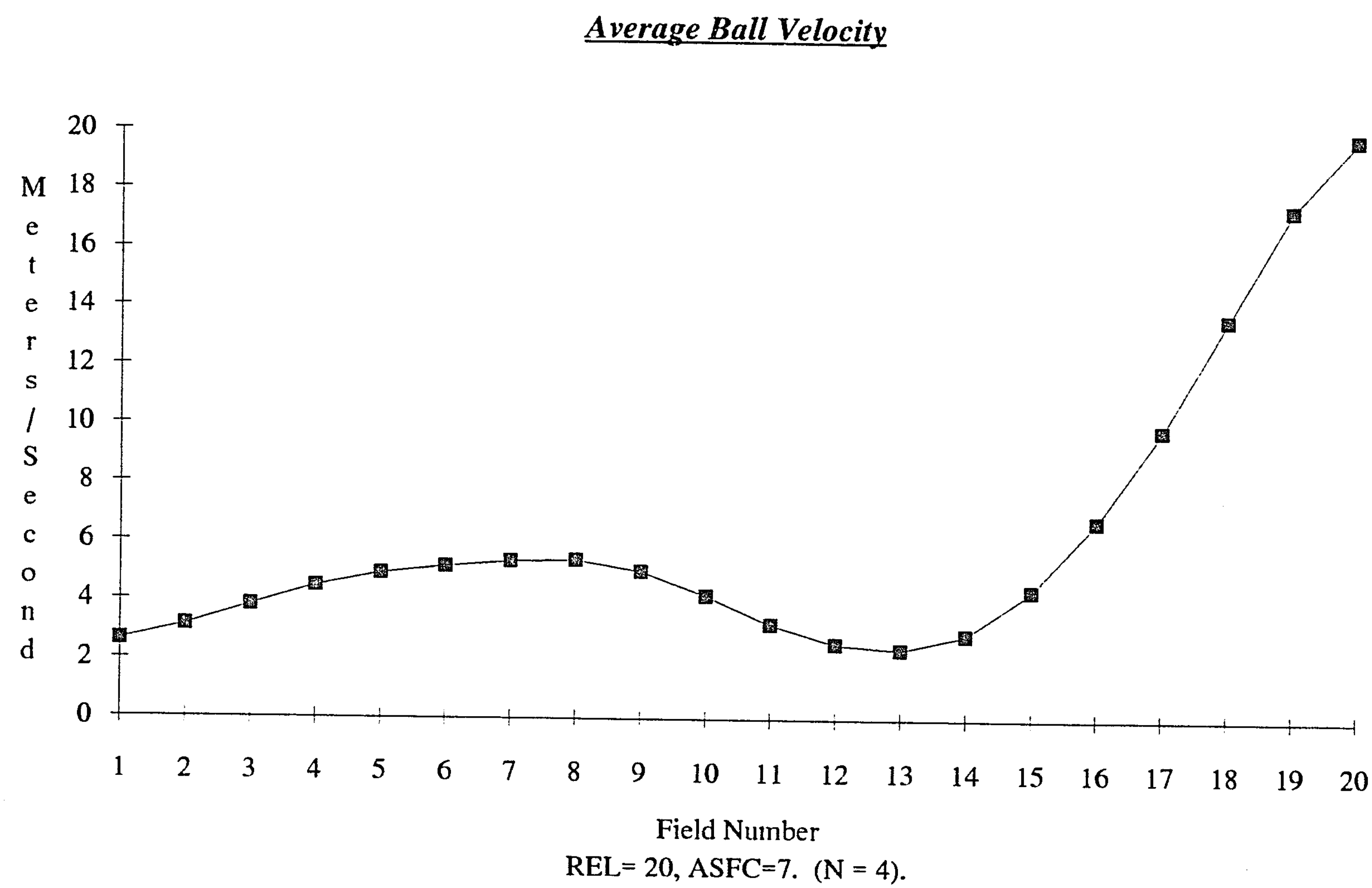


Figure 9. Average ball velocity from 340ms before release up to release.

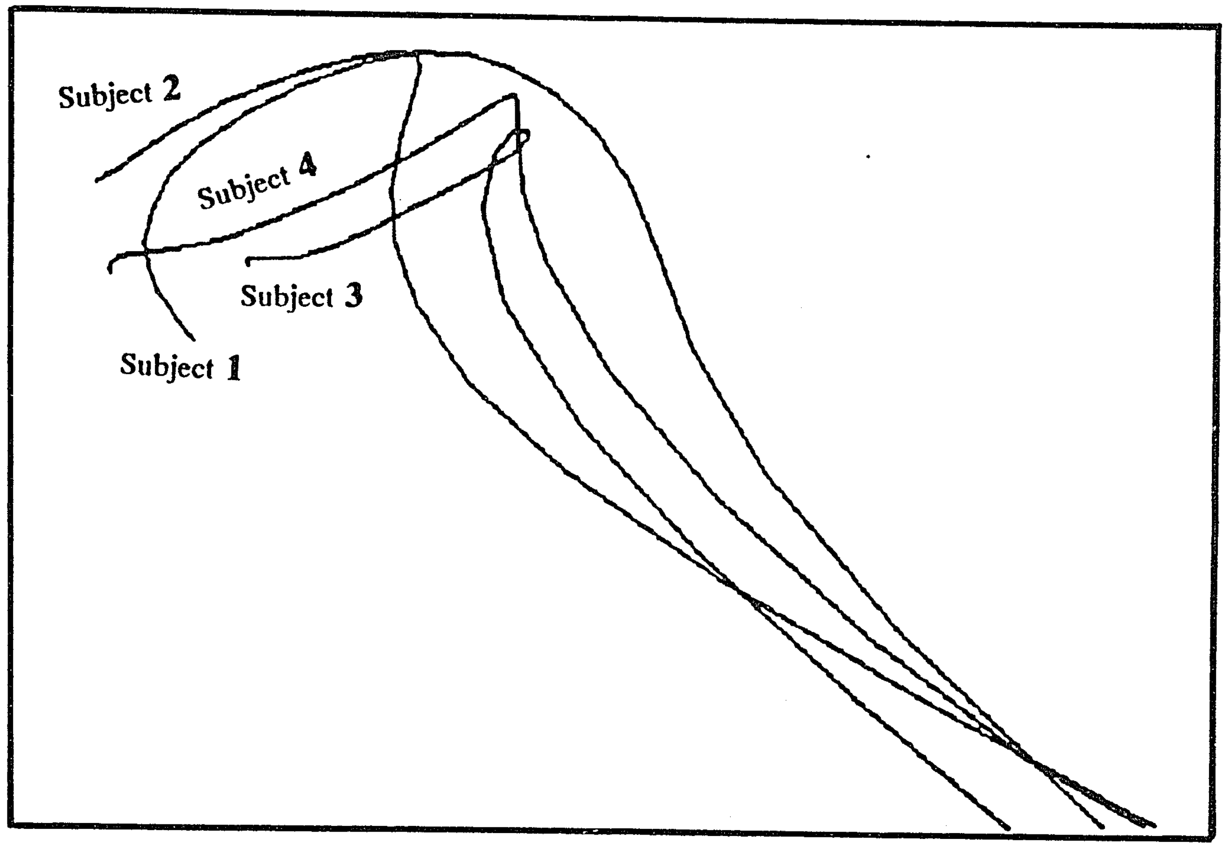


Figure 10. Overhead view of ball displacement from 340ms before release up to release (Overlay).

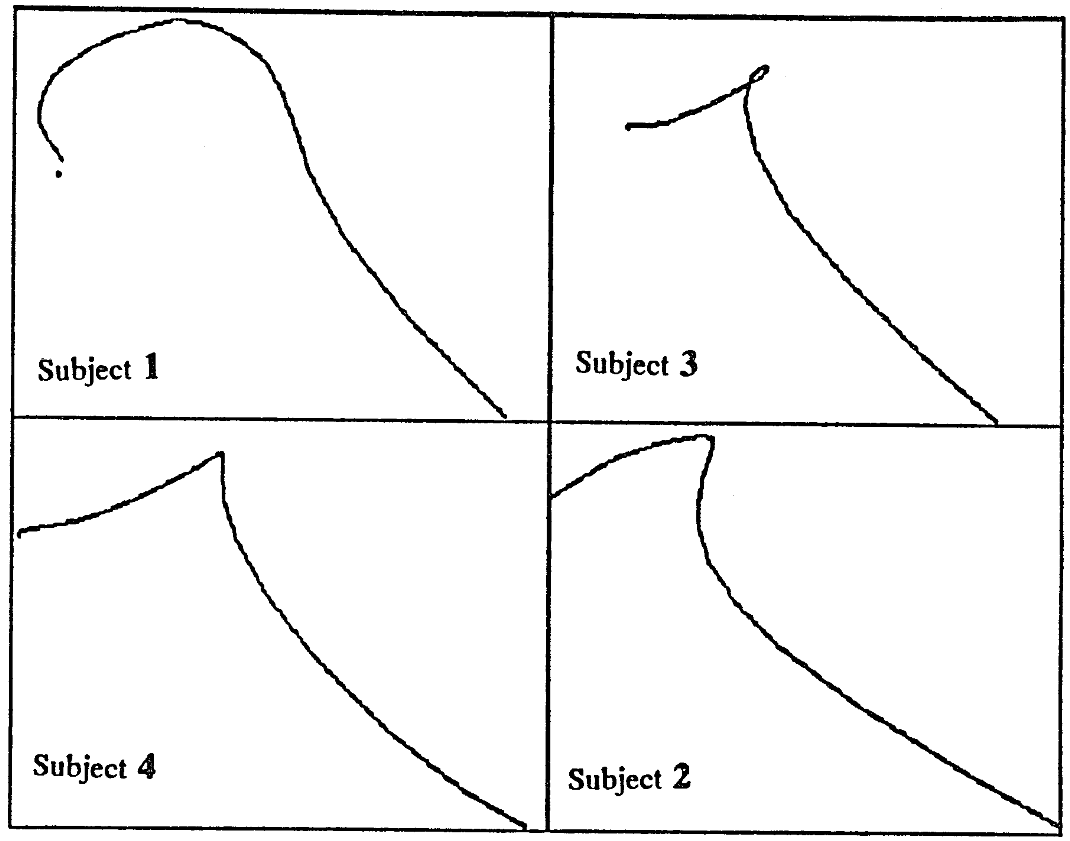


Figure 11. Overhead view of ball displacement from 340ms before release up to release (Individual).

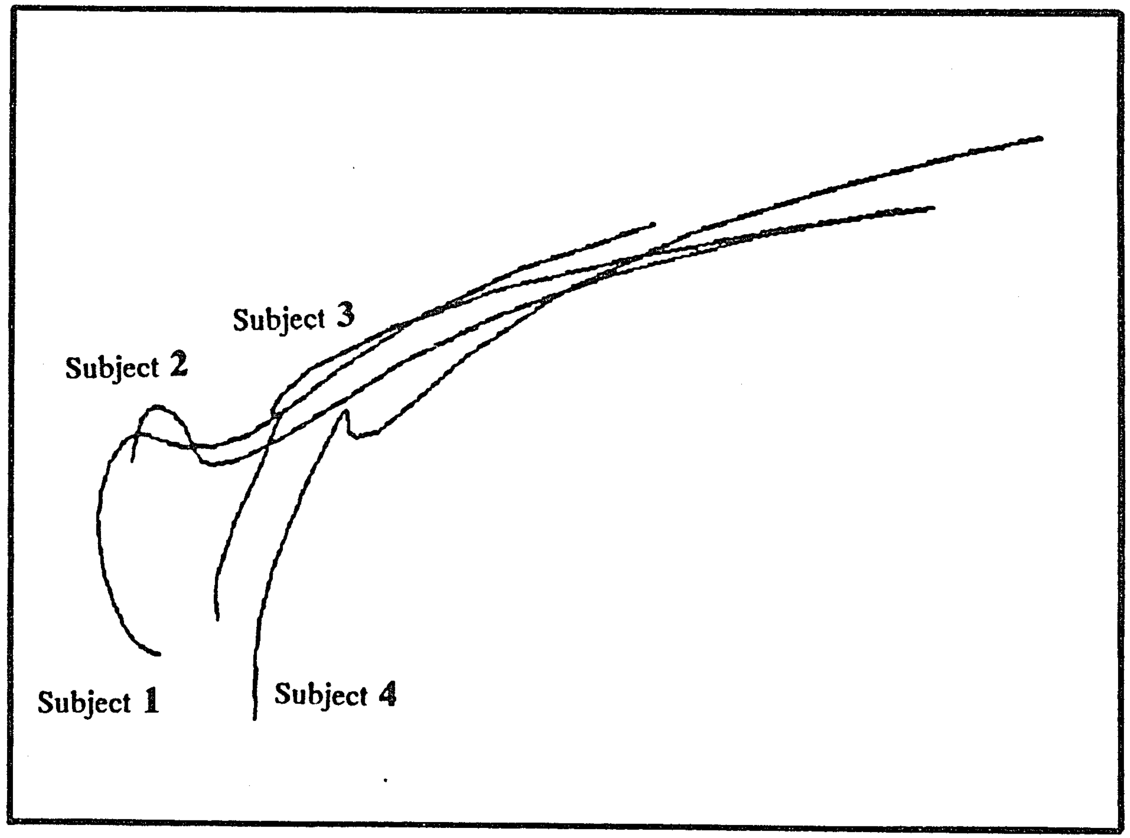


Figure 12. Side view of ball displacement from 340ms before release up to release (Overlay).

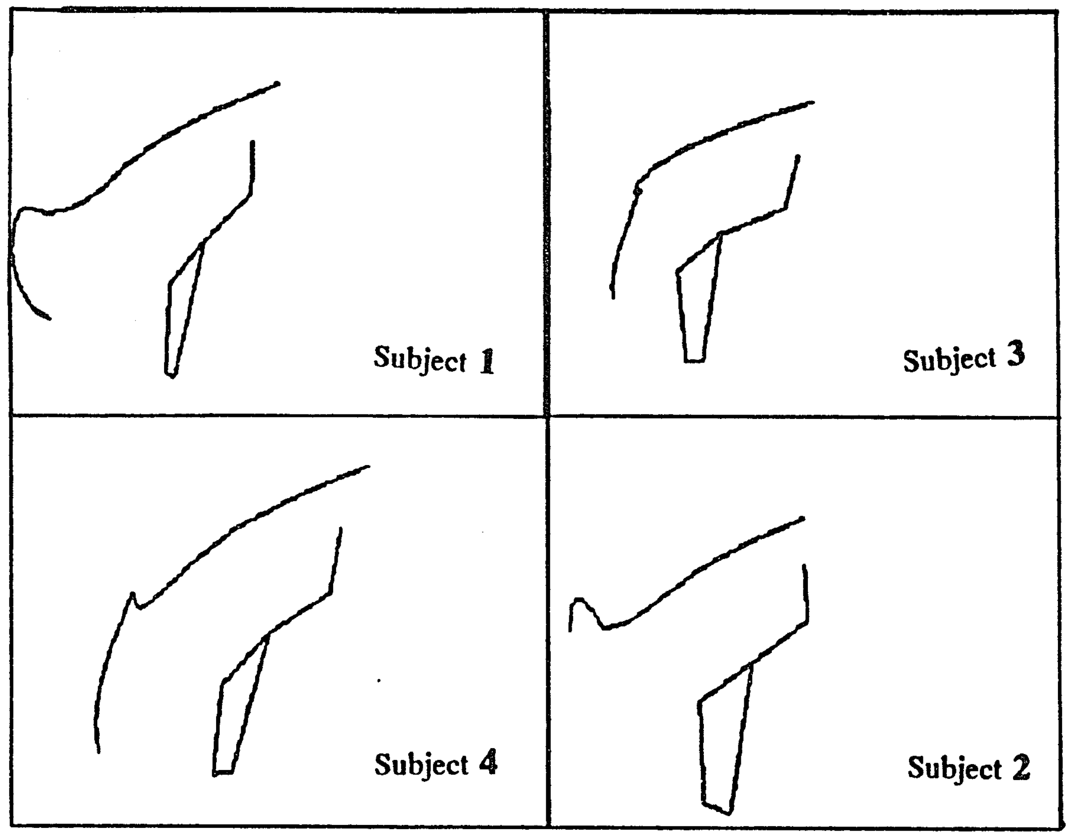


Figure 13. Side view of ball displacement with throwing arm and trunk from 340ms before release up to release (Individual).

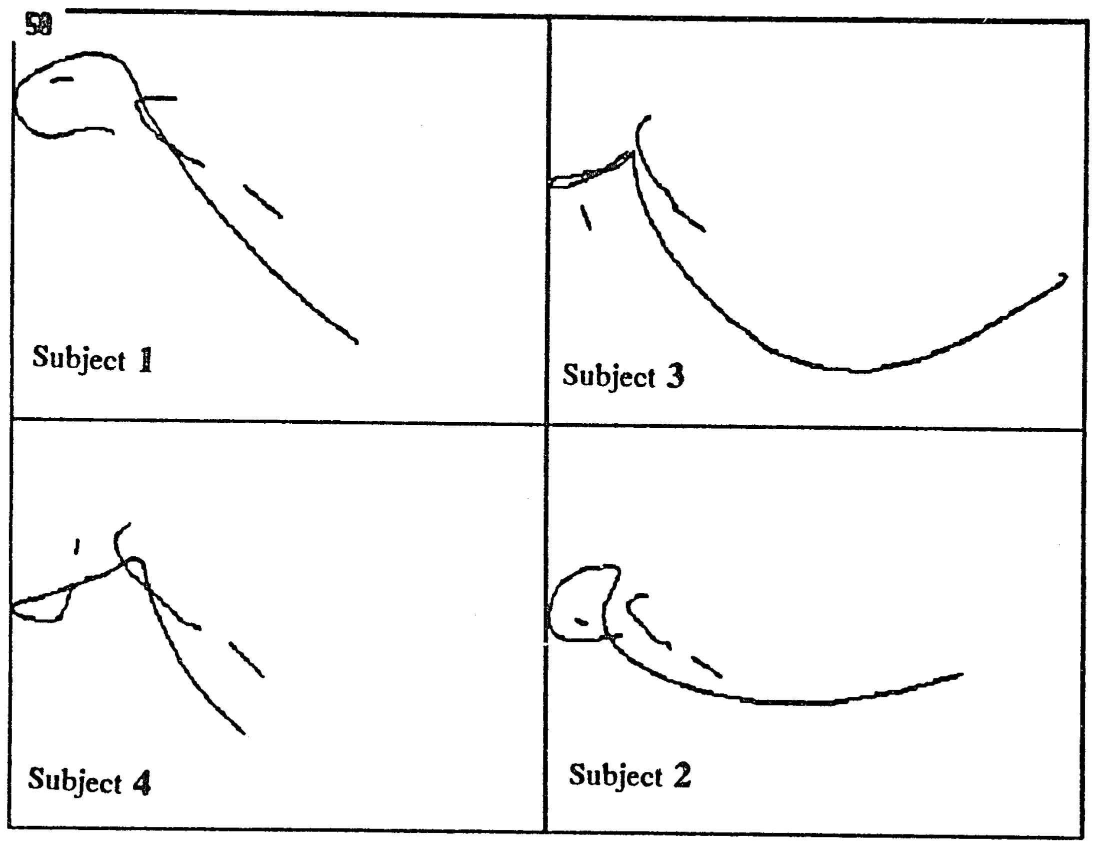


Figure 14. Overhead view of feet, center of mass, and ball displacement from fifth step of dropback up to release (Various times, Individual).

The mean distance the ball moved in the X plane, or backward to frontward direction, was 1.13m (3.71ft). As can be seen in Figure 14, subject one and two moved the ball backward before starting it on its forward path. In her study on the overarm throwing pattern, using softballs, Atwater (1970) reported the mean distance the ball traveled in the front to back direction to be 4.87 feet in the 300ms before release. The mean distance the ball traveled in the Y plane, or vertical direction, was .640m (2.10 ft) in the present study. Figure 15 indicates that subjects one and four showed slight initial lowering of the ball while the remaining two subjects did not. The figures produced by all subjects were shorter than that reported by Atwater (1970) where mean displacement in the vertical direction was 3.74 ft (1.14m), also in the 300ms before release. Figure 15 also shows a characteristic described by Atwater (1970) as a slight dip in the path of the ball common to all. Displacement in the Z plane, or right to left direction, was calculated from the farthest point, either left or right, at any time before release. This mean distance was 0.373m (1.22 ft). Subjects one, three, and four demonstrated a right to left direction, while subject 2 demonstrated a left to right direction. The mean distance in Atwater's (1970) study again was greater, 2.78ft (.85m).

The data in the present study illustrate that a football undergoes less movement in all three planes before release than does a softball or baseball. The extent to which this may be caused by the size and shape of the ball is not known, but Atwater (1979) did suggest that "the size and weight (415g) of the ball cause the passer to keep his hand behind the ball, which possibly restricts the range of the preparatory actions" (p. 56). The objective of the throw may also play a role as well. In the studies that used a softball or baseball (Atwater, 1970; Feltner, 1984, 1987) the subjects were concerned with maximum effort in terms of ball velocity. The influence of throwing at a target versus throwing at a backstop or to a person has to be considered. As Yessis (1984) mentioned the less

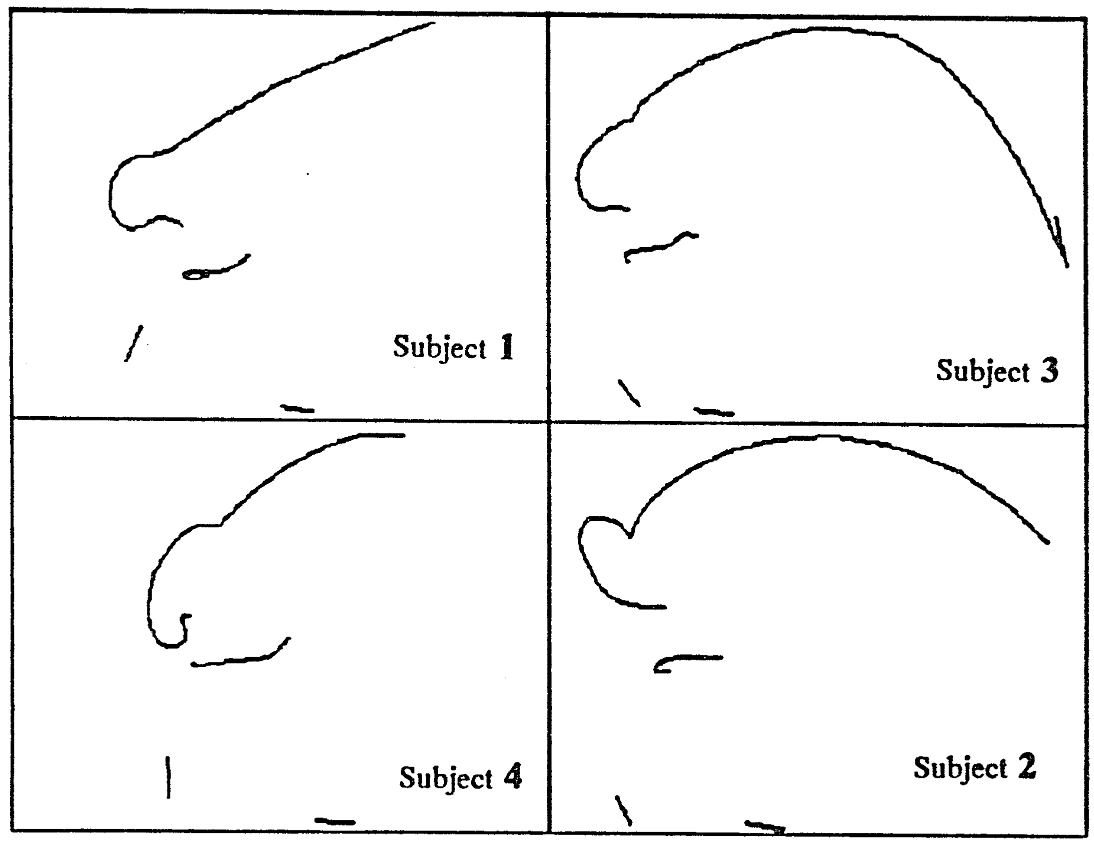


Figure 15. Side view of feet center of mass and ball displacement from fifth step of dropback up to release (Various times, Individual).

movement of the ball before release, the less chance the preparatory actions could cause inaccuracy.

The linear displacement of the center of mass (COM) is reported in terms of the Z (side to side) plane. The counterclockwise rotation of pelvis, trunk, and shoulder girdle caused the COM to move to the right (M = .204m & SD = .050m). This was followed by a shift back to the left (M = .036m & SD = .035m). Whether this was caused by the follow through, lateral deviation of the spine, or the completion of counterclockwise rotation is not known. What the data points out is that there was slight side to side movement during the throw which could be an indication of inefficiency.

The mean stride length was .751m (2.47 ft), shorter than that reported by Atwater (1970), but was longer than that suggested by Verduzco (1991), who suggested a 12 to 24 inch stride. The mean distance of stride foot deviation, a focal point for this investigation, was .199m (.653ft). Because the throwing motion was not aligned with the X axis, which defines the direction of the movement, the X/Z coordinate plane had to be rotated. To gain accurate measures the X axis was rotated to run through the path of the ball. An assumption was made that the rotated X axis, the path of the ball, and the mid-line between the thrower and the target were synonymous. The measure for stride foot deviation was calculated by the change in the X coordinate data produced by the Peak Performance Motion Analysis System at the left ankle because the left toe pointed slightly inward while the heel pointed slightly outward along the longitudinal axis of the left foot. The toe-in-heel-out orientation of the left foot agrees with results reported by Verduzco (1991).

The correlation between the placement of the stride foot and the accuracy of the throw was -.149. Other data about the COM and the amount of hip rotation may help in the interpretation of the significance of stride foot placement. It would be most mechanically sound to have the net force, which can be observed as the COM, moving as directly as possible toward the target. In the present study subjects' COM moved approximately eight inches to the right and just over an inch back to the left. It may be suggested that if a larger off-line placement were taken the net force, or COM, would be allowed to move forward in a more linear fashion. The fact that the hips were some 30° short of reaching the front facing position (a 90° rotation) at release, may be another factor that suggests a larger off-line placement of the stride foot. Hay (1985) indicated that the off-line placement allowed the hips to be more completely rotated. A greater lateral distance may allow a fuller rotation by the hips, although they may never achieve a full 90° rotation.

Angular Displacements and Velocities

The mean angle of elbow extension of the throwing arm at stride foot contact was 85.93°, with a standard deviation of 21.05°. This angle increased for all subjects to a mean of 130.72° with a standard deviation of 3.67° at release (Figures 16 and 17). These measures are not in agreement with the results stated by Verduzco (1991) when he reported elbow extension at release to be 170-175°. These results are, however, close to those published by Wick, et al. (1991), who compared the kinematic parameters of high school pitchers and high school quarterbacks, and Rash and Shapiro (1992) who studied eight quarterbacks who had participated in the Senior Bowl from 1990-1991. Both of these studies reported a mean elbow extension angle at release of 124°.

The mean angular velocity of elbow flexion/extension at stride foot contact was -37.86°/s with a standard deviation of 126.98°/s. The mean angular velocity at release with 1225.52°/s (SD = 77.05°/s) (Figures 18 and 19). Wick, et al. (1991) reported a slightly faster elbow extension velocity of 1716°/s.

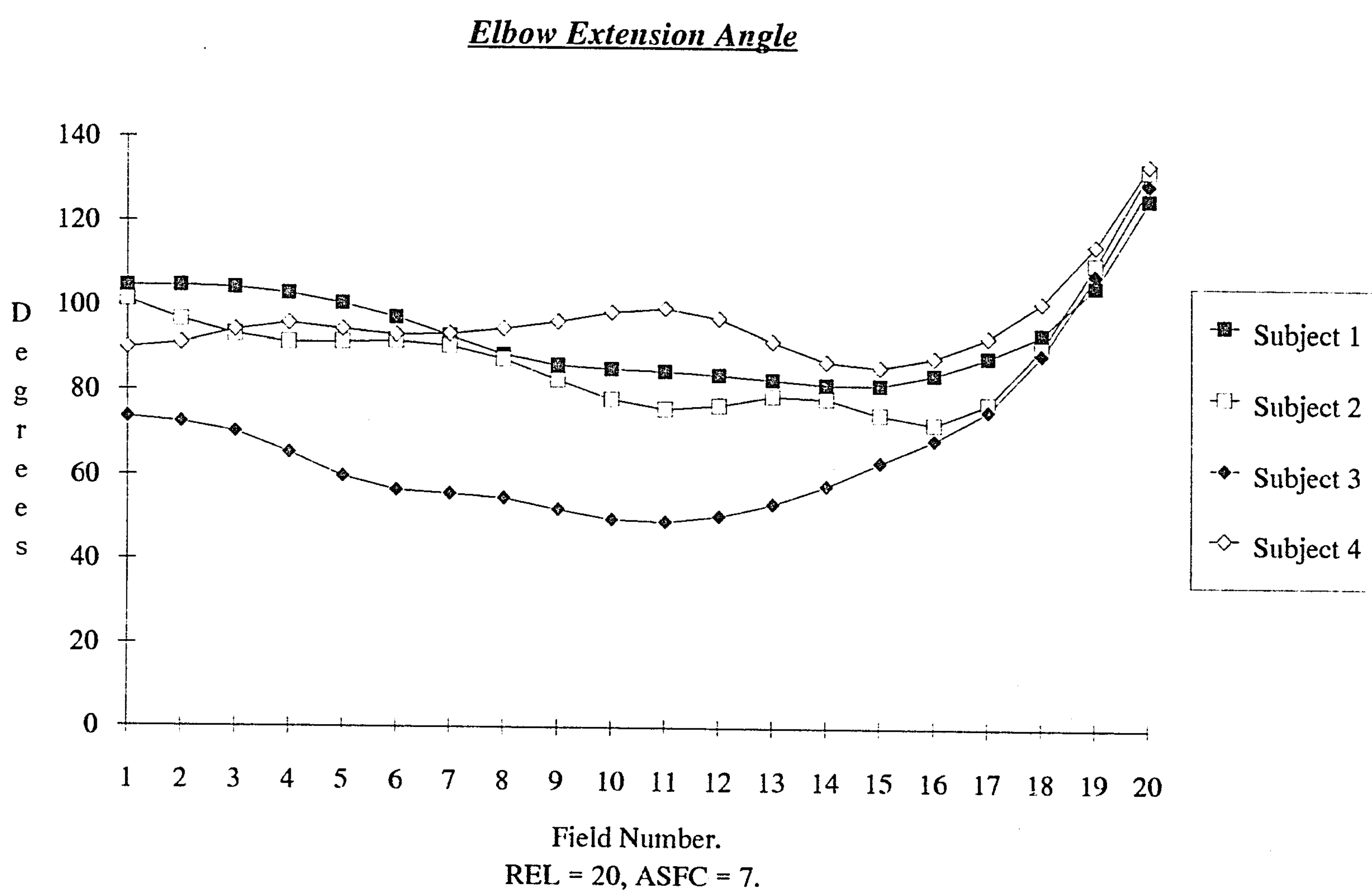


Figure 16. Elbow extension angle from 340ms before release up to release.

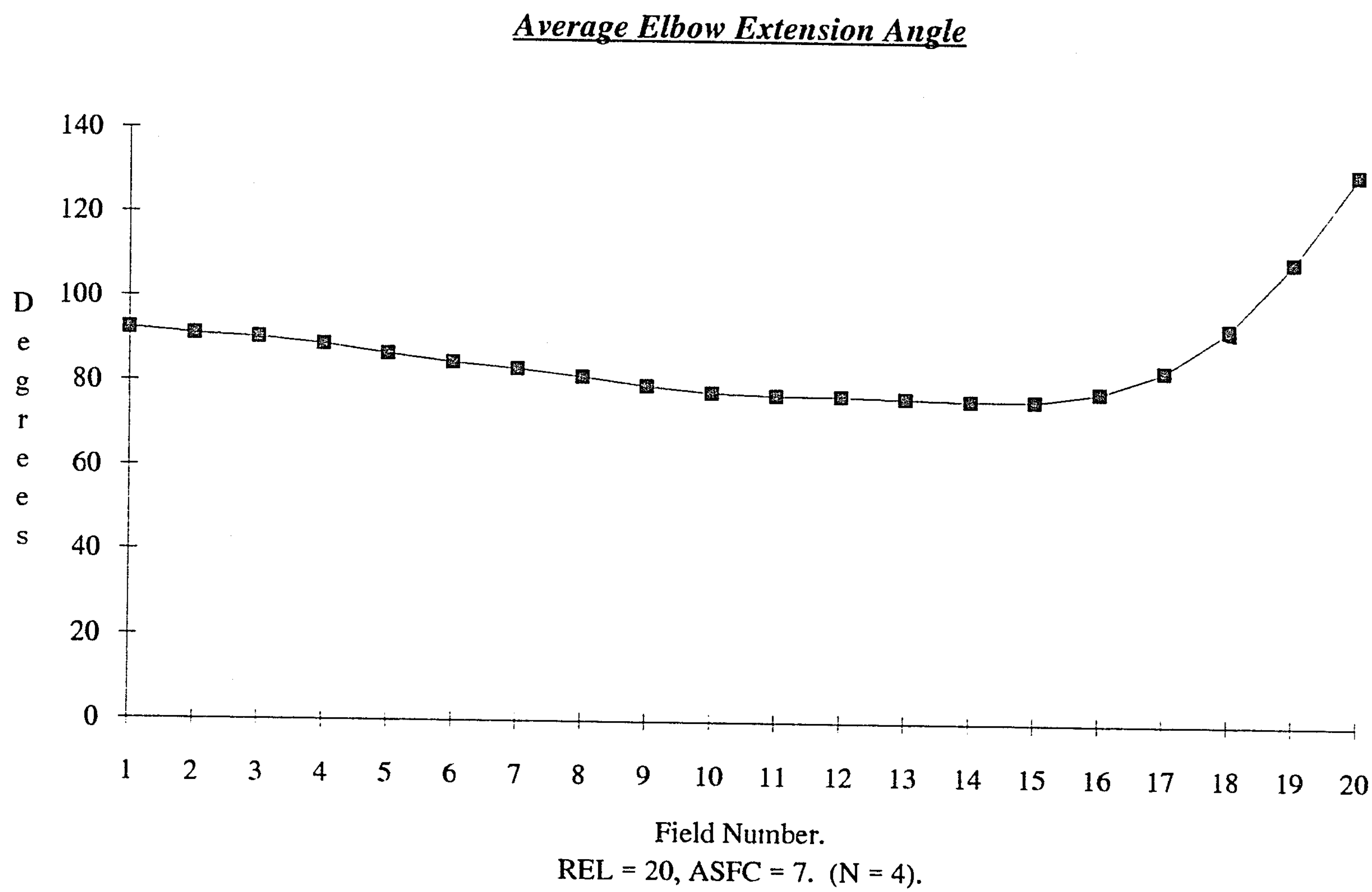
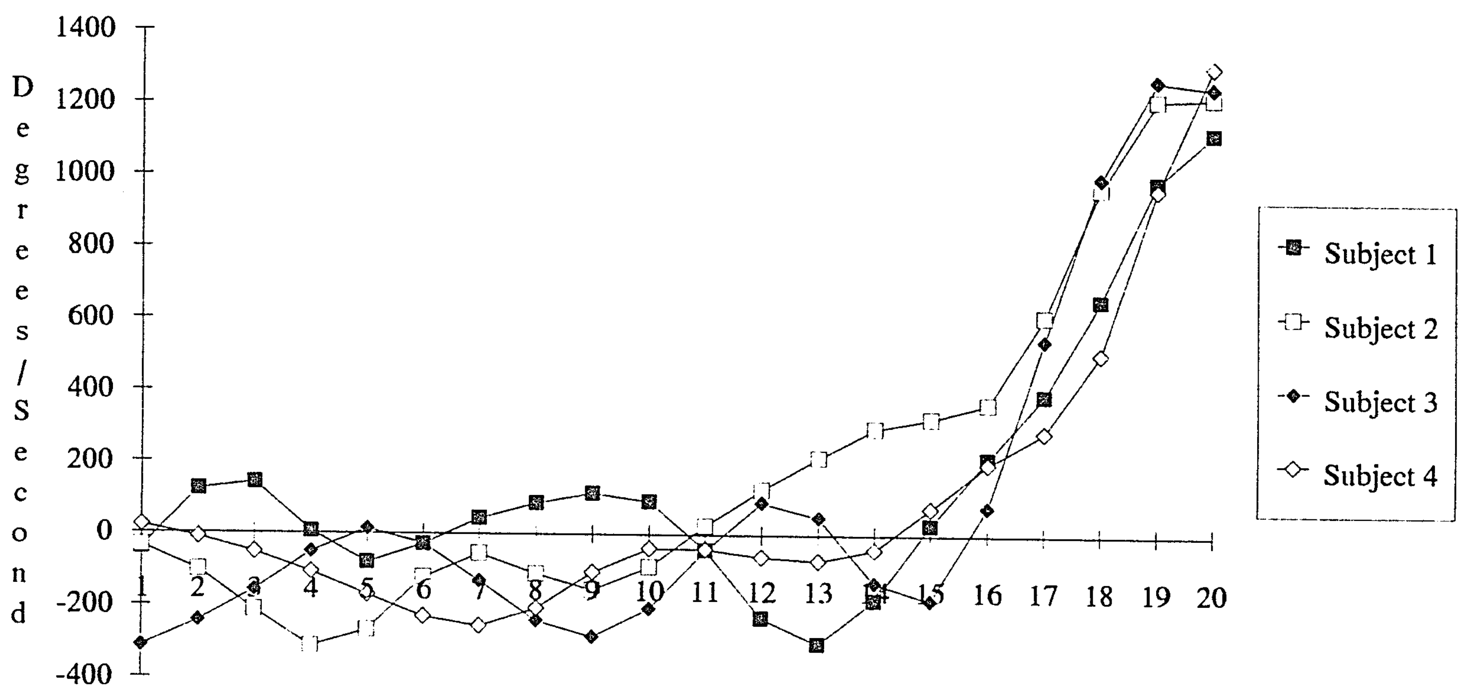


Figure 17. Average elbow extension angle from 340ms before release up to release.

Elbow Extension Velocity



Field Number.
REL = 20, ASFC = 7.

Figure 18. Elbow extension velocity from 340ms before release up to release.

Average Elbow Extension Velocity

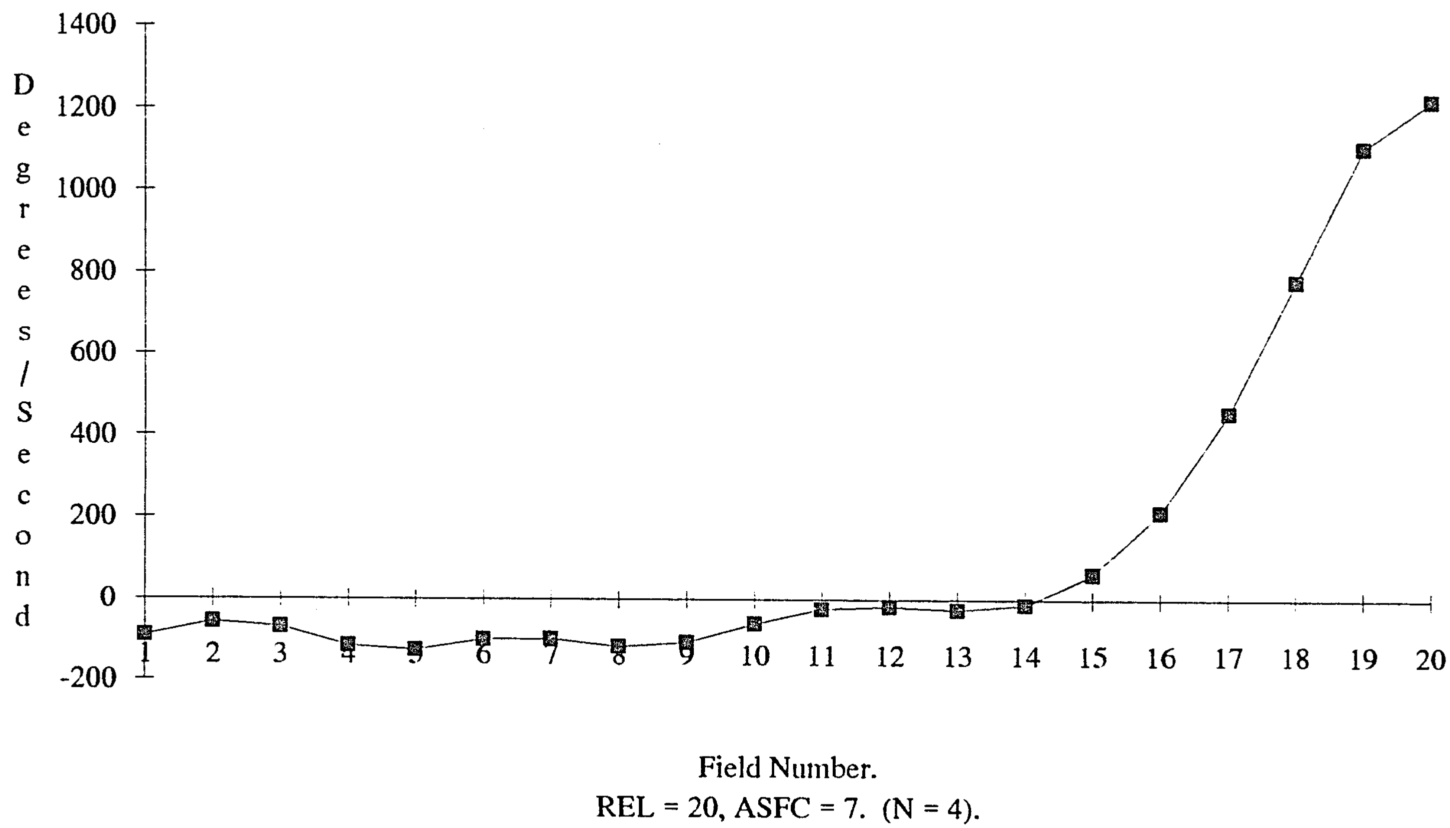


Figure 19. Average elbow extension velocity from 340ms before release up to release.

The mean shoulder abduction angle at the moment of stride foot contact (SFC) was $^{-}.463^{\circ}$ with a standard deviation of 8.638°. Wick, et al. (1991) reported an angle of 105°, which when translated to concur with the present study is 15°. At release (REL) the mean shoulder abduction angle increased so that the arm was raised slightly ($M = 8.295^{\circ}$, $SD = 7.933^{\circ}$) (Figures 20 and 21). Wick, et al. (1991) and Rash and Shapiro (1992) reported translated values of 24° and 11°, respectively. At stride foot contact the upper arm was in a horizontally abducted position ($M = {}^{-}19.5^{\circ}$, $SD = 7.853^{\circ}$), while at release it had moved forward to a horizontally adducted position ($M = 15.75^{\circ}$, $SD = 5.56^{\circ}$) (Figures 22 and 23). Wick, et al. (1991) reported $^{-}2^{\circ}$ at stride foot contact and 21° at release, while Rash and Shaprio (1992) reported 17° at release. At the moment of stride foot contact the upper arm was in a position of internal rotation although the range was large ($M = 22.917^{\circ}$, $SD = 29.968^{\circ}$) (Figures 24 and 25). The throwing arm then externally rotated to its maximum ($M = {}^{-}83.75^{\circ}$, $SD = 11.442^{\circ}$) at 85ms prior to release and then internally rotated until, through, and after release. The mean externally rotated position of the upper arm at release was $^{-}44.103^{\circ}$, with a standard deviation of 6.878°. Wick, et al. (1991) reported an internally rotated position of 2° at stride foot contact, a maximum external rotation of $^{-}78^{\circ}$, and an externally rotated position of $^{-}55^{\circ}$ at release. Rash and Shapiro (1992) reported a maximum external rotation of $^{-}72^{\circ}$ and an externally rotated position of $^{-}41^{\circ}$ at release. Mean maximum internal rotation velocity was found to be 2790.25°/s and occured 25ms after release. This value is almost half of that found by Wick, et al. (1991) which was 4586°/s, but was relatively close to that found by Rash and Shapiro (1992) 2348°/s which occured 33ms after release. The present study found internal rotation velocity at release to be 1177°/s. Rash and Shapiro (1992) reported 1199.86°/s.

__Shoulder Adduction/Abduction__

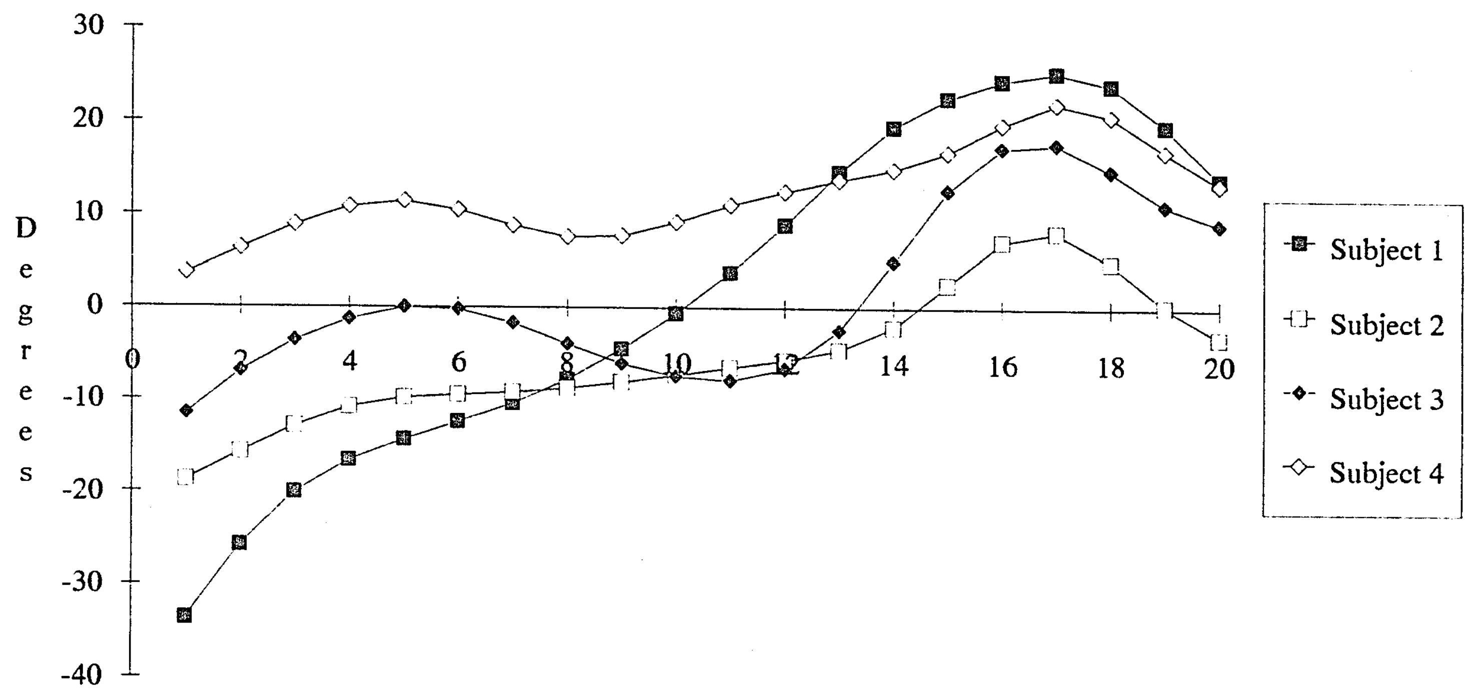


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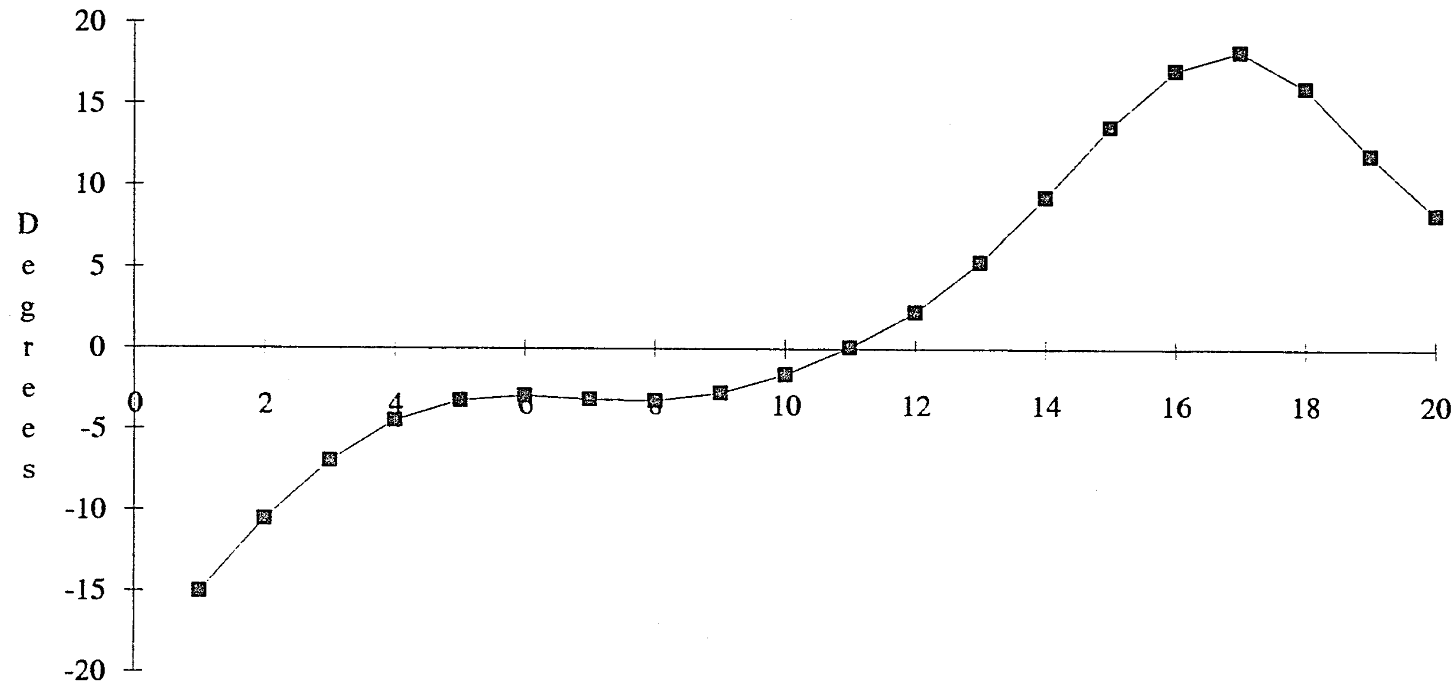
__Figure 20__. Adduction/abduction of the upper arm from 340ms before release up to release.

Average Adduction/Abduction of the Upper Arm at the Shoulder



Field Number.
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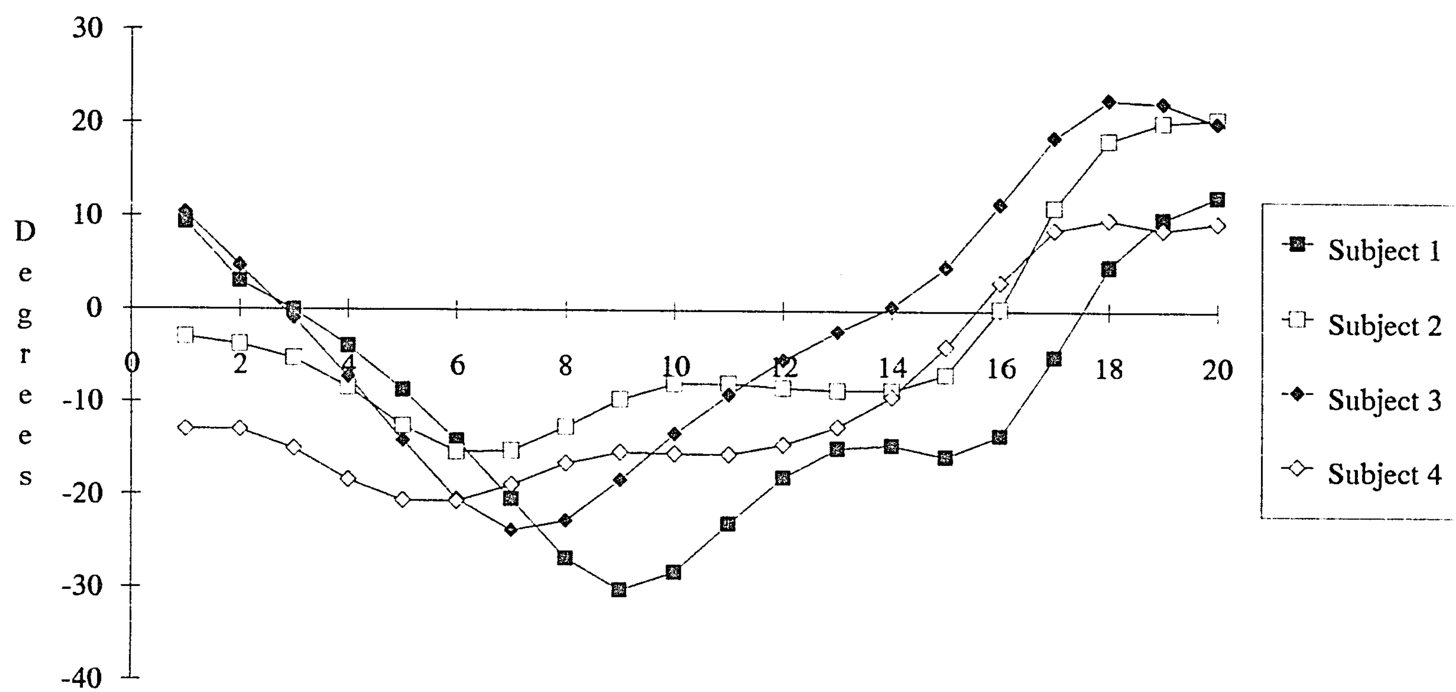
Figure 21. Average adduction/abduction of the upper arm from 340ms before release up to release.

Horizontal Adduction/Abduction



Field Numbers.
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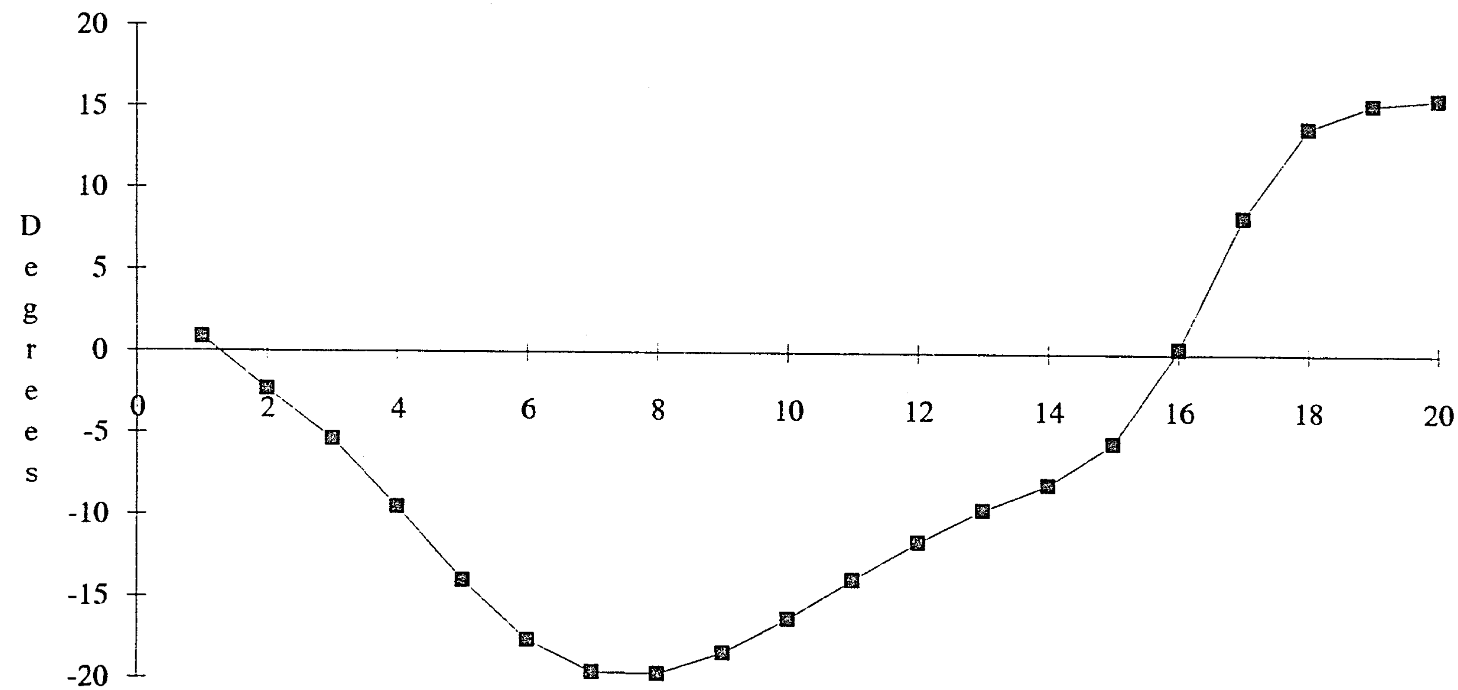
Figure 22. Horizontal adduction/abduction of the upper arm from 340ms before release up to release.

Average Horizontal Adduction/Abduction of the Upper Arm



Field Number.
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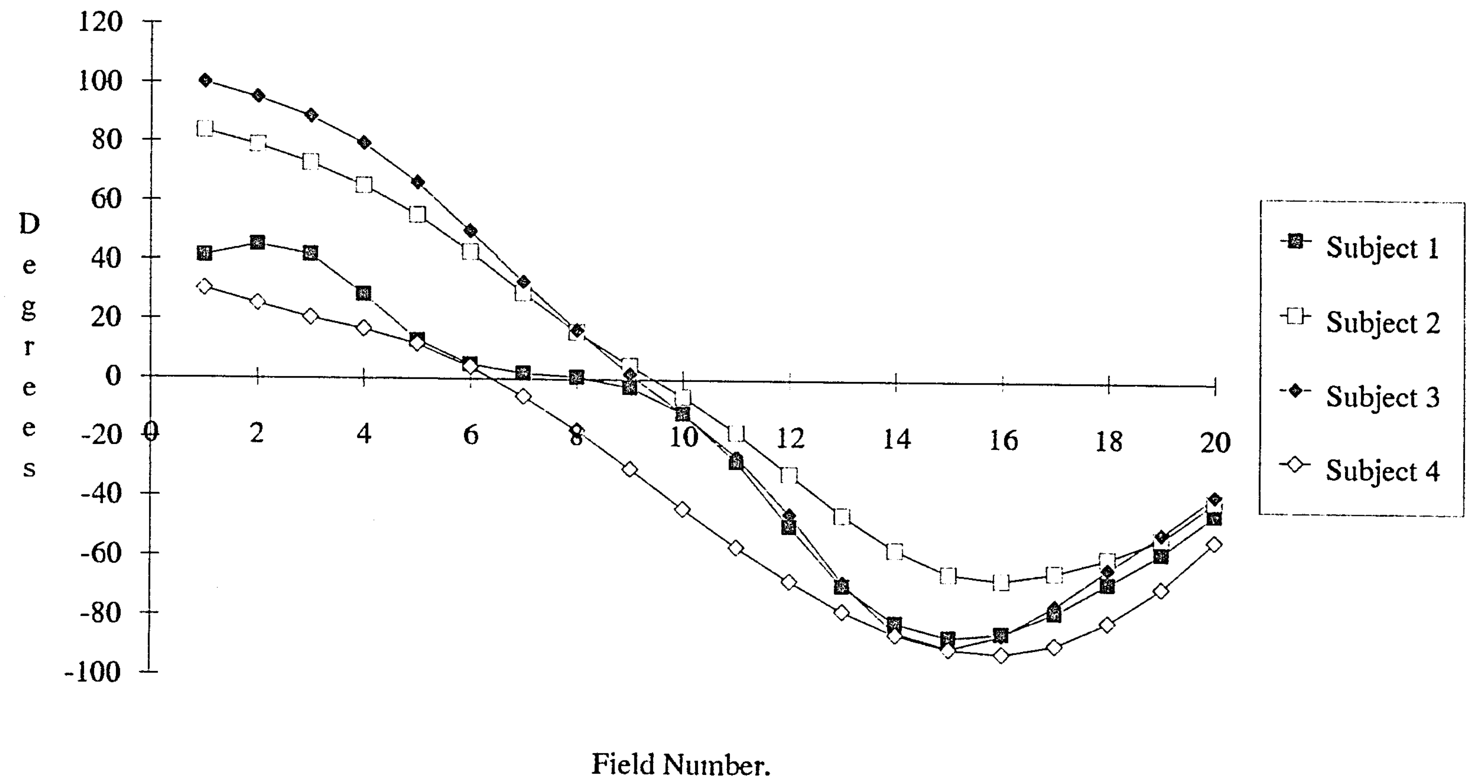
Figure 23. Average horizontal adduction/abduction of the upper arm from 340ms before release up to release.

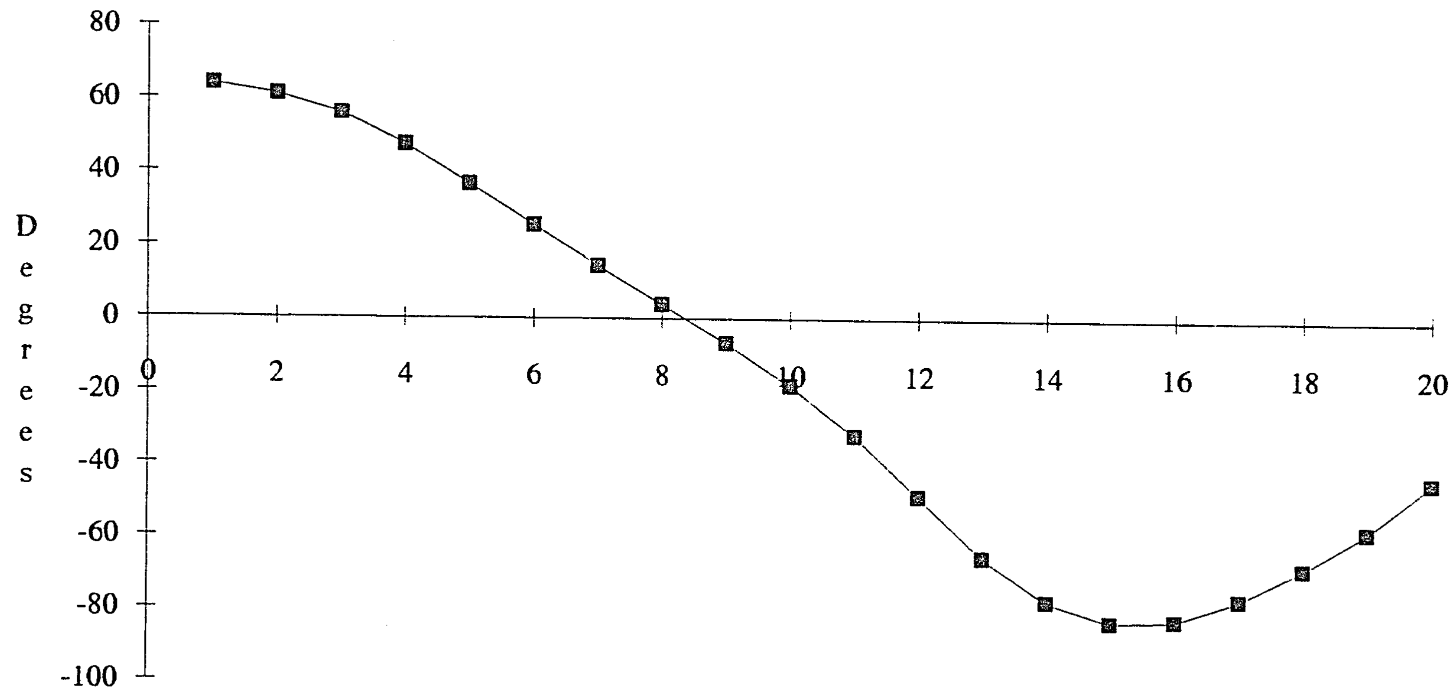
Internal/External Rotation of the Throwing Arm



REL = 20, ASFC = 7.

Figure 24. Internal/external rotation of the throwing arm from 340ms before release up to release.

Average Internal/External Rotation of the Throwing Arm



Field Number.
REL = 20, ASFC = 7. (n = 4).

Figure 25. Average internal/external rotation of the throwing arm from 340ms before release up to release.

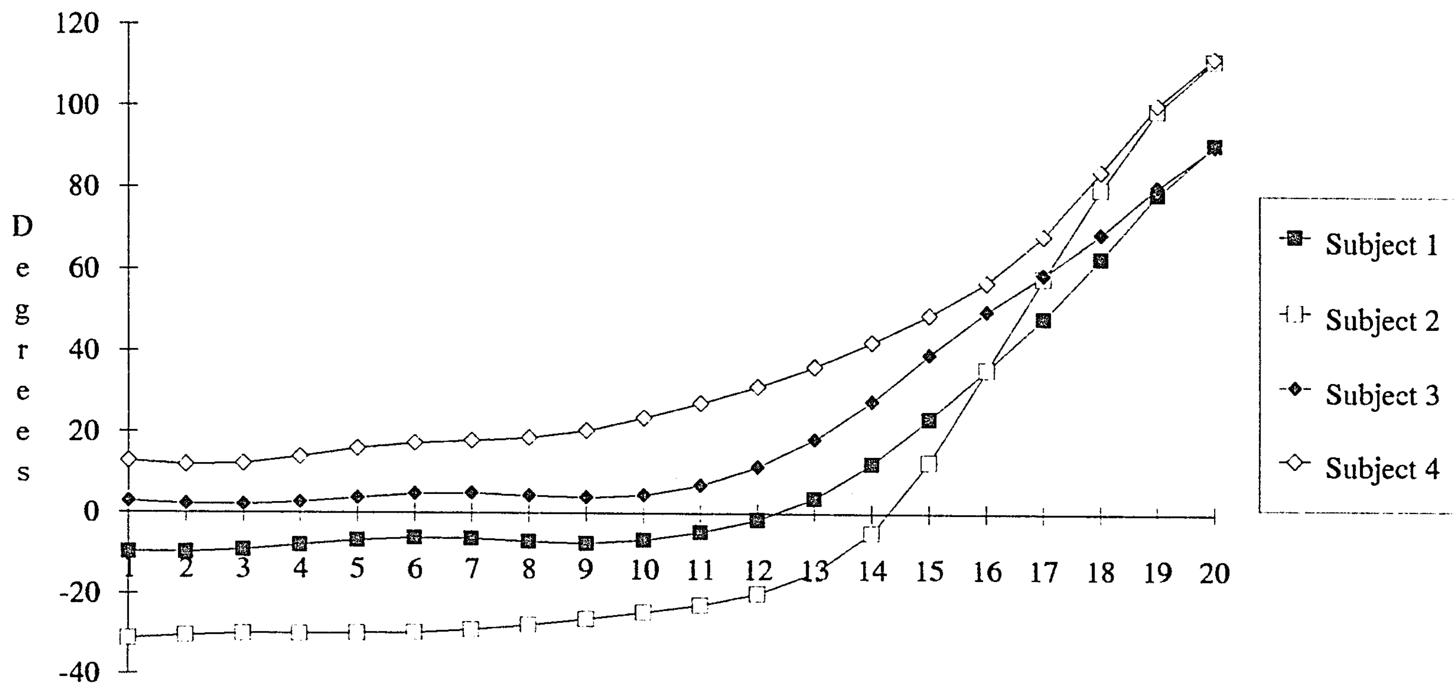
The average angular displacement of the shoulders was 104.5° from stride foot contact to release. At stride foot contact the shoulders lagged behind the hips by 22.25° (Figures 26 and 27). After stride foot contact, the shoulders rotated counterclockwise catching and surpassing the hips to be 41.0° ahead of the shoulders at release. The maximum angular velocity of the shoulders was 771.25°/s and occured 42ms before release. This is slightly less than that reported by Wick, et al. (1991), at 1017°/s.

The average angular displacement of the pelvis was 41.75° from stride foot contact to release (Figures 28 and 29). Maximum angular velocity was found to be 374°/s which occured 115ms before release. This is slower than the 518°/s found by Wick, et al. (1991). The shoulder and pelvis sequence is consistent with the Kinetic Link System.

The mean extension angle of the stride, or left leg when it contacts the ground was 131.59° with a standard deviation of 3.508°. From this point of stride foot contact until release the stride leg extended to 152.768° with a standard deviation of 6.394° (Figures 30 and 31). These data are different from that reported by Verduzco (1991) where extension at release was 175°. The data in the present study approximates the data reported by Wick, et al. (1991) who reported an angle of 148° for their quarterbacks at release. Mean angular velocity at the stride knee at stride foot contact was 20.261°/s with a standard deviation of 28.056°/s. This velocity increased to a value at release of 254.102°/s, standard deviation of 37.325°/s.

There is a discrepancy between the present study's results and Verduzco's (1991) results with respect to the throwing elbow and left knee extension angles. This study showed that the entire body works in a wheel-axel configuration. Krieghbaum and Barthel's (1990) analogy that the overarm throwing motion works like a bull whip illustrates that no part of the bull whip above the handle is rigid. If the left knee and/or the throwing arm were to extend to full extension, 175° to 180°, at or before release as

Shoulder Rotation Angle



Field Number.
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Figure 26. Shoulder rotation angle from 340ms before release up to release.

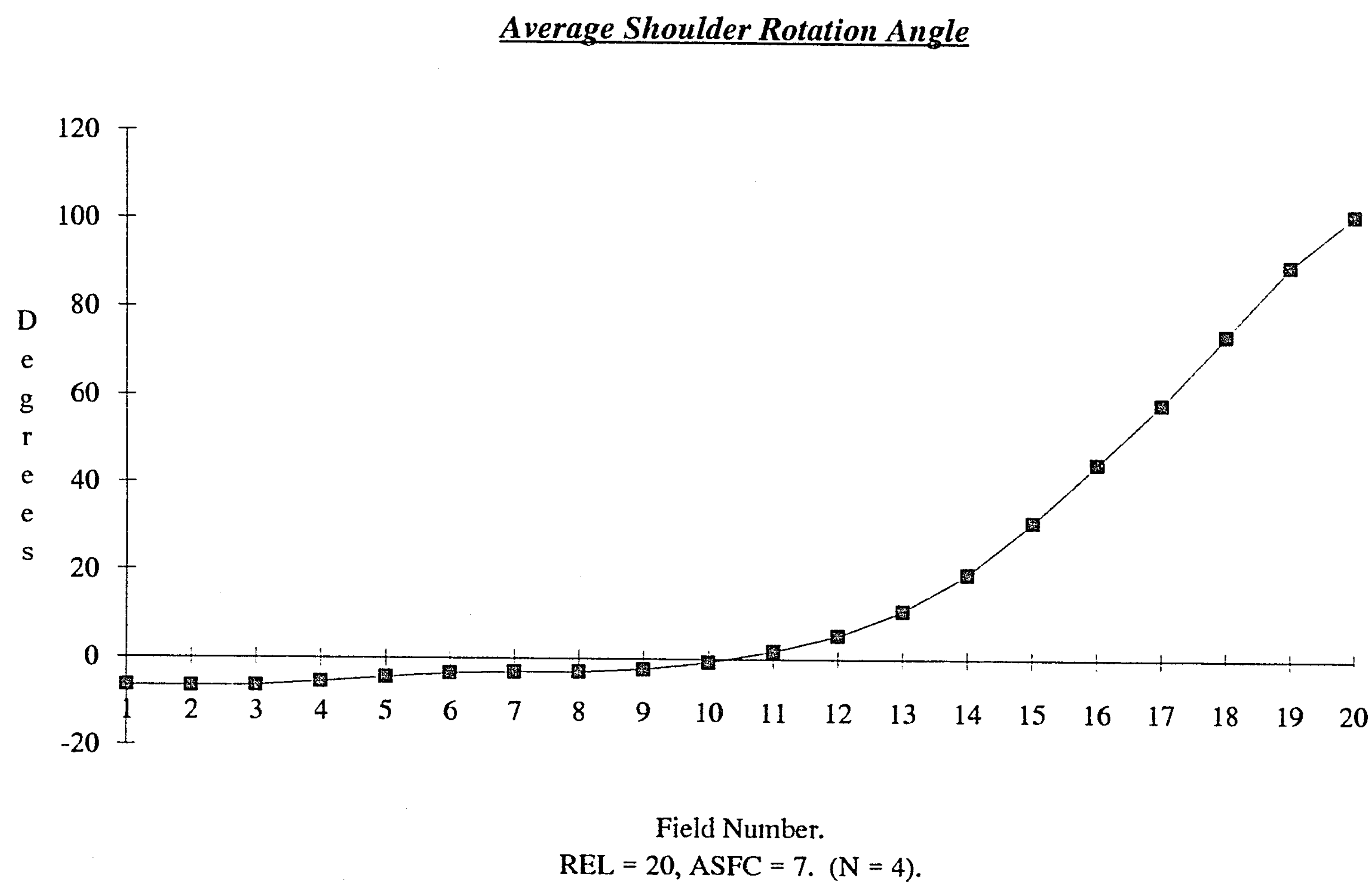


Figure 27. Average shoulder rotation angle from 340ms before release up to release.

Hip Rotation Angle

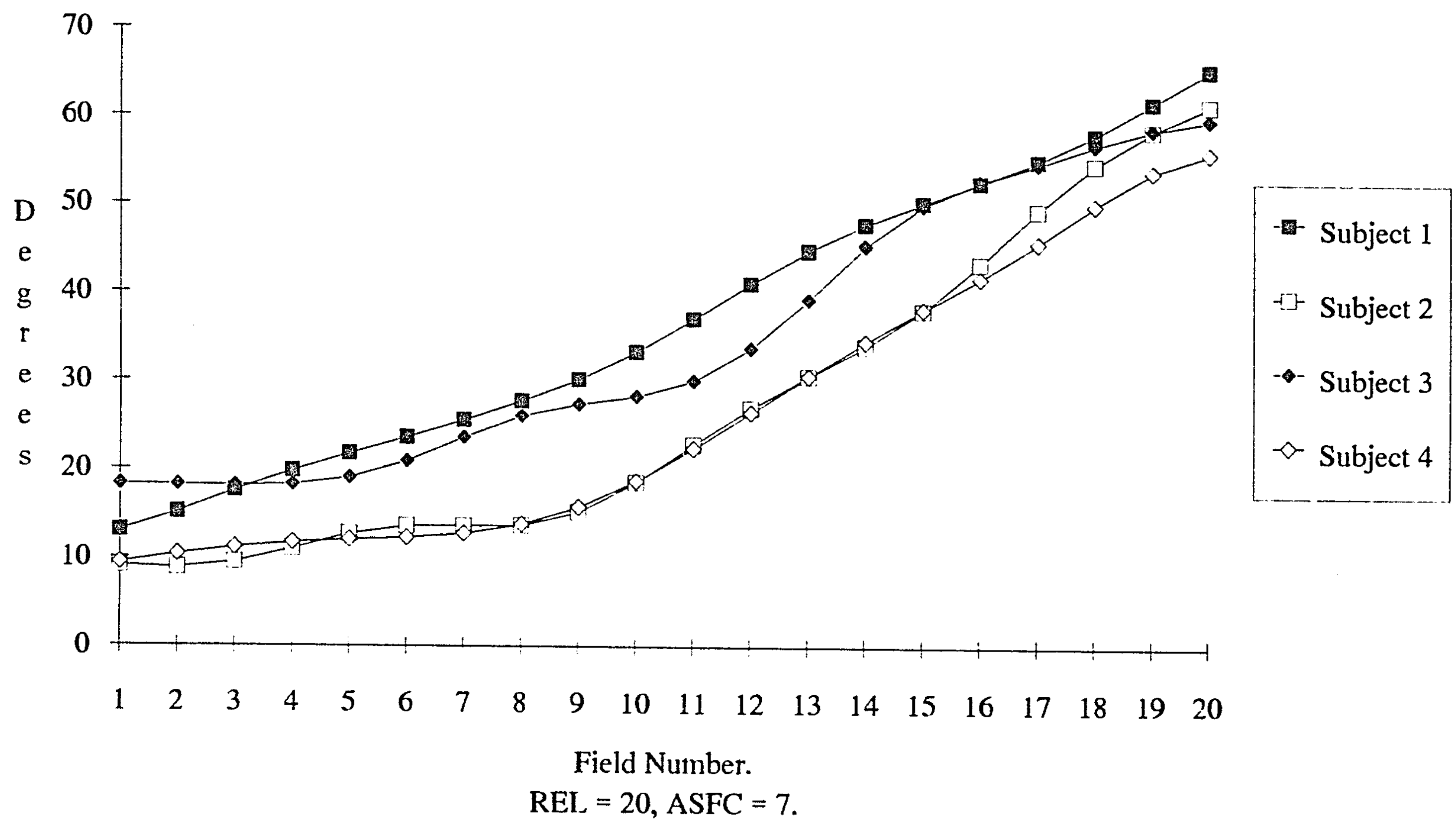


Figure 28. Hip rotation angle from 340ms before release up to release.

Average Hip Rotation Angle

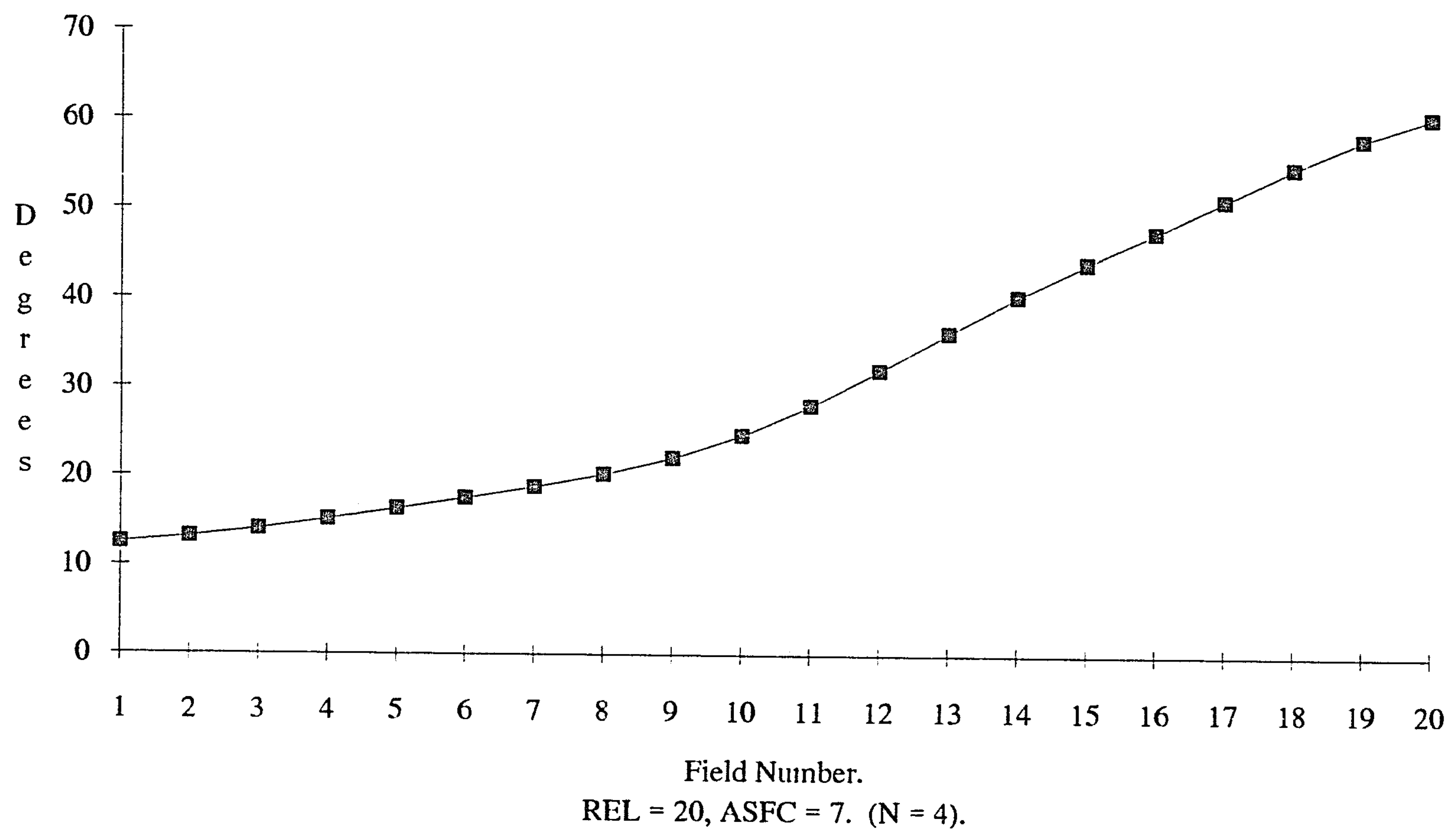


Figure 29. Average hip rotation angle from 340ms before release up to release.

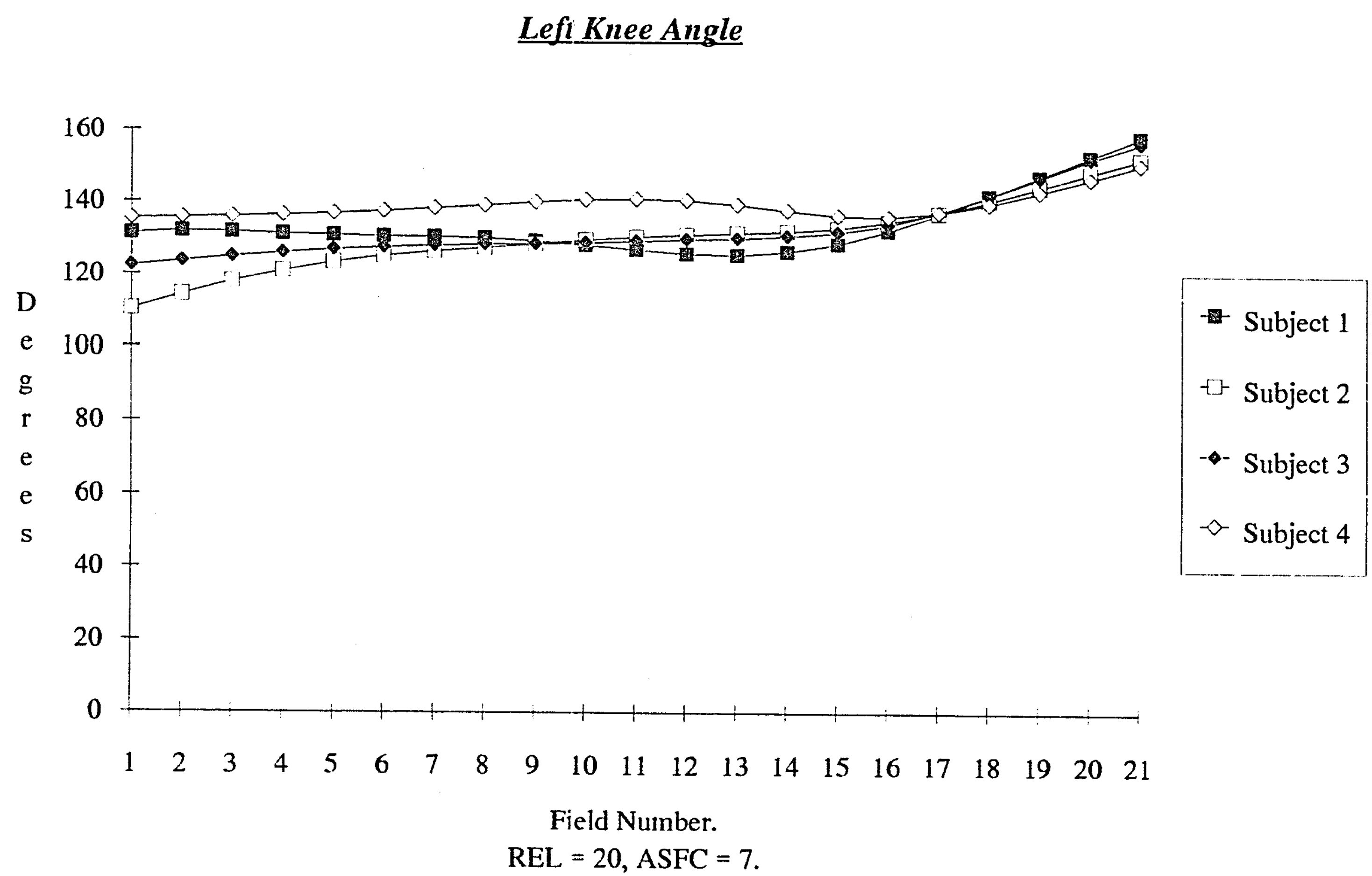
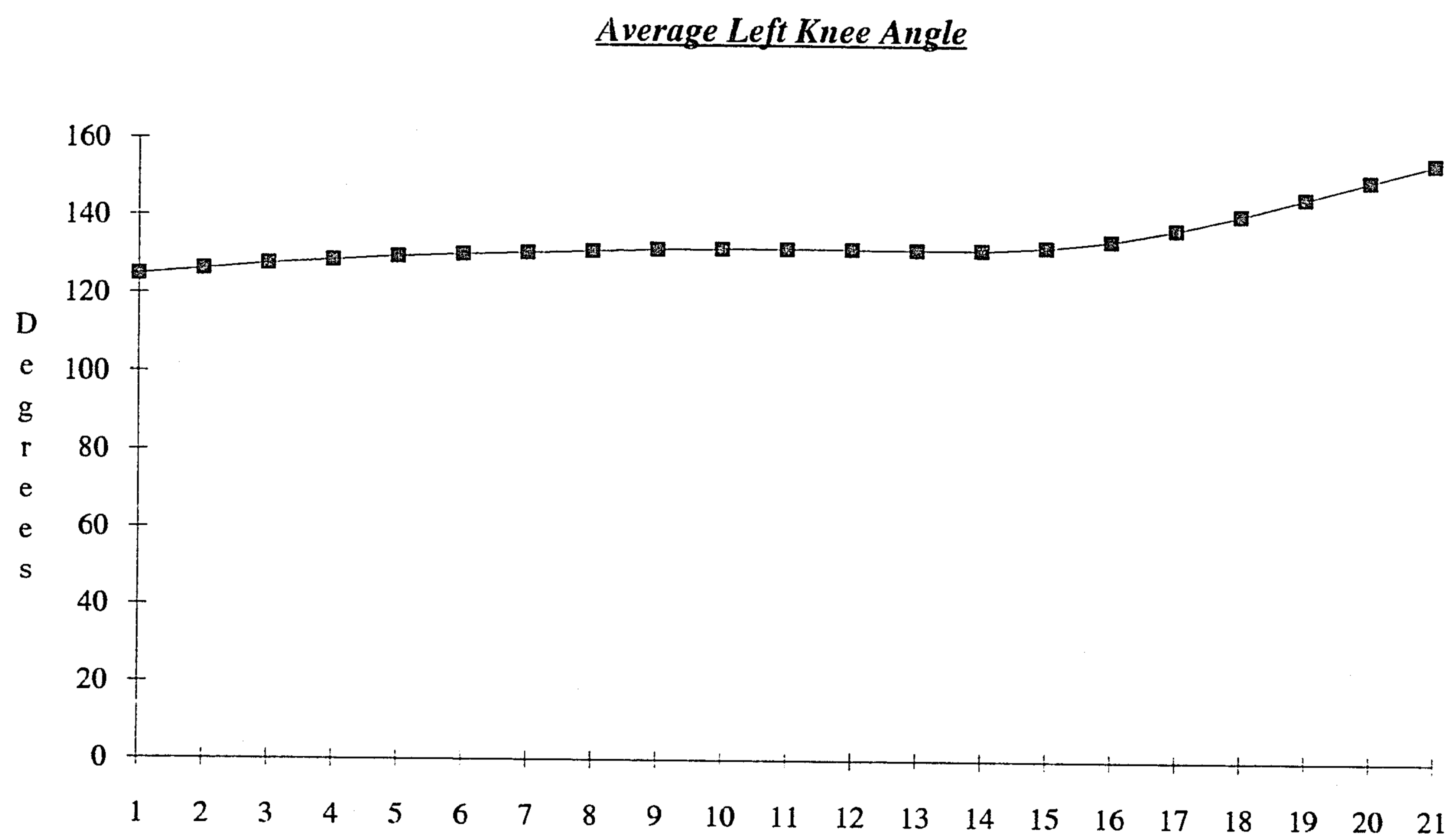


Figure 30. Left knee angle from 340ms before release up to release.



Field Number.
REL = 20, ASFC = 7. (N = 4).

Figure 31. Average left knee angle from 340ms before release up to release.

Verduzco (1991) suggested there would be a rigid lever in the system. As was mentioned before a wheel-axel system produces two and a half times the velocity of a lever system. Full extension of the throwing arm makes it a rigid lever and is therefore less efficient when under a load, such as the mass of a ball. Observation of the various overarm throwing/striking patterns has lead to the reafirmation that elbow extension is dependent on the load which may or may not be applied (Krieghbaum & Barthels, 1990). It appears that the throwing arm elbow is less extended when throwing a heavy object like a basketball compared to the near full extension of the elbow during a volleyball serve or spike. Skills that require no load, like a volleyball serve or spike, have the greatest amount of extension at the elbow and the degree of extension decreases as the load increases (i.e., badminton racquet, football, basketball).

Trunk Orientation

Other studies on the throwing motion, particularly baseball, have included both medial/lateral lean and anterior/posterior lean. Medial lean and posterior lean measures are not presented here because the subjects did not demonstrate them.

There was no trend in the lateral lean angle before stride foot contact, probably due to the different drop back techniques used. Some subjects righted themselves to 0^{o} at some point before stride foot contact, while others did not. As the stride foot contacted the ground the mean lateral lean angle (away from the throwing arm) was -6.325^{o} and continued to increase until it reached a mean of -29.75^{o} at release. Wick, et al. (1991) reported an angle of $^{-}67^{o}$ at release. This large discrepancy could be due to the calibration frame which was estimated to be level in the present study. The speed of this lateral lean did not have a common trend except that a major decrease occurred just after (17ms) the ball was released.

The anterior lean angle showed little similarity among the subjects especially at release where the standard deviation of 6.384^{o} was larger than the mean of 5.075^{o}. Wick, et al. (1991) obtained a larger value of 18^{o} for anterior lean. The mean for the anterior lean at stride foot contact was 11.375^{o} and decreased to 5.075^{o} at release. To fully understand this measure other measures of central tendency need attention. The range of anterior lean was from 0.2^{o} to 14.2^{o}, consequently one subject increased his anterior lean after stride foot contact, but two subjects decreased this angle to almost 0^{o}. The speed of the anterior lean did decrease in all subjects starting at least 136ms before release.

Accuracy Correlation

The mean score of the five trials that hit the target was used as the dependent variable in the Pearson Product-Moment Correlation. Lateral deviation from the mid-line between the target and thrower was the independent measure. It must be noted that two of the subjects hit the target five out of five times and therefore the total number of throws for each was five. Two other subjects required additional throws to hit the target five times. One needed eight total trials while the other required ten total trials. Evaluation of the correlation coefficient revealed little relationship between the lateral deviation from the mid-line and accuracy of the throw ($R = {}^{-}.149$). The Statistical Power Analysis: A Computer Program by Michael Borenstein and Jacob Cohen was used to calculate the power of the correlation. With a sample size of four and an alpha two tailed test set at .05, the correlation must be .961 or larger in order to be significant. A significant relationship will be hard to find until larger groups can be studied. This may have to be done at a lower skill level, probably high school, where a larger pool can be gathered, or over a longer period of time to allow a larger pool of high level data to be gathered.

CHAPTER V

Summary and Recommendations

Summary of Joint Actions

The descriptions that follow are divided by timing markers and apply to throws of the same length as those used in the present study (22 meters or 25 yards). The timing markers used in this study were initiation of movement, stride foot contact, and release. Inititation of movement was defined as either the first forward motion of the stride leg or the first backward movement of the football, stride foot contact occurs when the stride foot contacts the ground, and release is the first instant the ball is out of the throwing hand. These descriptions start after the quarterback has taken a five step drop.

Summary of The Joint Actions That Constitute the Overarm Football Throw

Inititation of Movement. This study confirmed that the hand/ball starts its three dimensional motion in preparation for acceleration. The football, in the right hand, begins its backward and upward movement until it reaches a position behind the head and shoulders. The joint actions responsible for this are upper arm abduction and horizontal abduction. During this time the velocity of the ball increases as it is moved backward and upward. The ball undergoes a backward displacement of approximately 0.181m before starting forward during early and late acceleration which occurs 90ms before stride foot contact. These actions are consistent with those reported by Atwater (1970) who studied subjects throwing baseball/softballs. The subjects in Atwater's (1970) study moved the ball through a greater range of motion than those in the present study. Because of the time constraints present and the fact that in the present study two quarterbacks produced similar velocity without lowering the ball, the initial backward movement should be kept on at least the same horizontal level from which it started. This characteristic is supported by Verduzco (1991). The two subjects who lowered the ball while moving it backward took the longest time to release the ball, approximately 119ms longer. Lowering the ball during its backward movement is a characteristic granted to those skills that are free from time restrictions, which could be a cross over characteristic from baseball throwing skills and demonstrates inefficiency. Inefficiency results due to excess movement that is not necessary for the production of force nor the accuracy of the throw. Yessis (1984) adds support for this by stating, "The number of movements and the range of the movements is related to accuracy" (p.6).

This study confirms Verduzco's (1991) recommendation that, at the initiation of movement, the hips and shoulders should be perpendicular to the target, or completely closed, to ensure that maximum velocity can be achieved by the counterclockwise rotations. As the left leg strides forward the hips start their counterclockwise rotation. These actions occur as the ball reaches its highest point in the backswing. In this study the hips rotated approximately 19^{o} from initiation of movement to stride foot contact. Atwater (1970) found similar results and stated, "All subjects began to rotate the pelvis forward, in the direction of the throw, before the left foot first contacted the floor in the forward stride" (p. 270). Kreighbaum and Barthels (1990) also support hip rotation before stride foot contact by stating, "As the leading heel approaches the ground, the pelvis begins its medial rotation about the longitudinal axis" (p. 613). This characteristic is slightly different than that suggested by Verduzco (1991) where he stated, "Through the first phase [up to stride foot contact] the transverse axis of the hips will remain, for the most part, pointed toward the target (12 o'clock). In other words, they [the hips] will remain in a closed position" (p. 113).

Stride Foot Contact. As Hay (1985) found with baseball pitching, this study showed that in football the stride foot must contact the ground slightly to the left of the thrower so that it will compensate for the change in COM position throughout the throw and provide the new axis of rotation for the hips. Kreighbaum and Barthels (1990) add, "This placement provides a new base for the forward moving CG [center of gravity]" (p. 625). Jensen et al. (1983) agree that an off-line placement "permits a greater distance over which to apply force which serves to increase final velocity" (p. 226-227). In this study the forward length of the stride varied with the length and velocity of the throw. For a throw approximately 22 meters (25 yds) in length a stride of about two and one half feet may be optimal. The longitudinal axis of the stride foot should have an oblique orientation. This toe in heel out orientation was also suggested by Verduzco (1991). Jensen et al. (1983) also suggested a toe in heel out orientation to insure that the net force applied to the ball will be "applied as directly as possible in line with the intended motion" (p. 227).

This study found the left knee is extended to some point so that the femur is above the position of being parallel to the ground. More specifically, the knee is extended 132^{o} and this angle will continue to increase throughout the remainder of the motion, however, it did not reach near or full extension. The hips started to rotate counterclockwise, approximately 19^{o}, while the shoulders remained, for the most part, perpendicular to the target at approximately $^{-}3^{o}$. The shoulders were slightly over closed at this point.

At this point in time the elbow began to flex past a position perpendicular to the ground. The upper arm began to raise, move backward horizontally, and rotated to the front slightly past perpendicular with the ground (23^{o}). In this study as the throwing arm rotated backward the ball's velocity decreased rapidly and began to move downward slightly. The throwing arm continued to abduct, horizontally abduct, and externally rotate to its largest value, 18^{o}, $^{-}19^{o}$, and -84^{o} respectively, at different points in time before release at which point the throwing arm adducted, horizontally adducted, and internally rotated at a high rate of speed. The thrower laterally flexed his spine, to the left, which, according to Atwater (1970) raises the plane in which the ball is rotated forward. The elbow extended rapidly (1331°/s) increasing the resultant ball velocity.

Release. This study showed that the position of the feet remained the same, although the right foot may or may not come significantly off the ground after release during the followthrough (Figures 32 and 33). The left knee continued to extend to 153°, while the right knee flexed as it came off the ground. At release the hips, which rotated two thirds, 61°, of the way forward continued to rotate although at a decreasing rate throughout the followthrough. The trunk continued to lean farther to the left and the shoulders, which have rotated slightly passed the front facing position toward the target, 101°, continued to rotate at a decreasing rate throughout the followthrough.

The upper part of the throwing arm moved forward horizontally, horizontally adducted, although it remains behind the right shoulder. The upper arm moved into an abducted position and internally rotated to $^{-}44°$, although not enough to have reached a position of being perpendicular to the ground, 0°. The elbow extended to almost three quarters of full extension, 131° and continued extending throughout the followthrough but did not fully extend at any point.

Summary of Findings Related to Center of Mass

No other studies, to this date, have investigated COM as it relates to the overarm throwing pattern and especially to the football throw. This study showed that all subjects demonstrated a side to side shift in the path of the COM during the throw. This study suggested that the stride foot should contact the ground more than eight inches off the mid-line between the thrower and the target to straighten out the path of the COM during the throw, and therefore, better direct the net force directly toward the target.

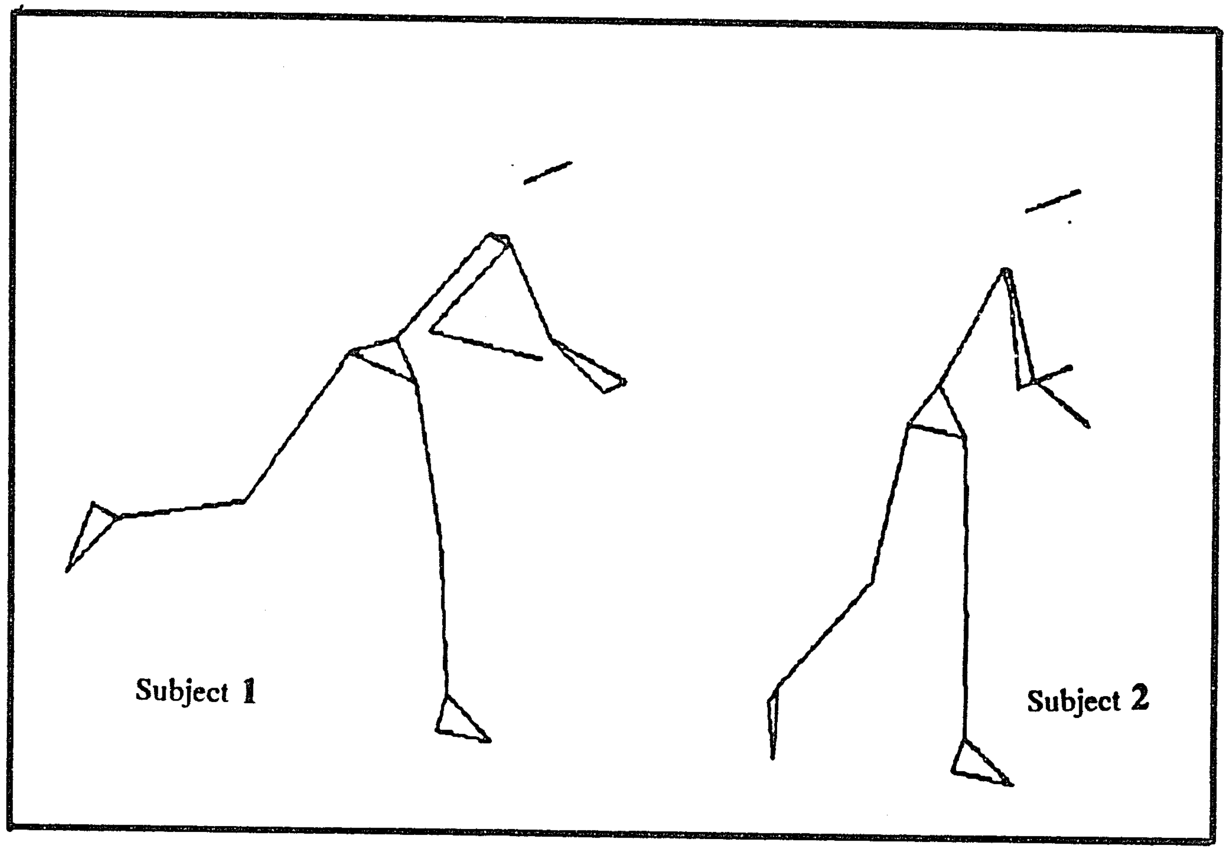


Figure 33. The degree to which the back foot is raised off the ground during the followthrough, two subjects.

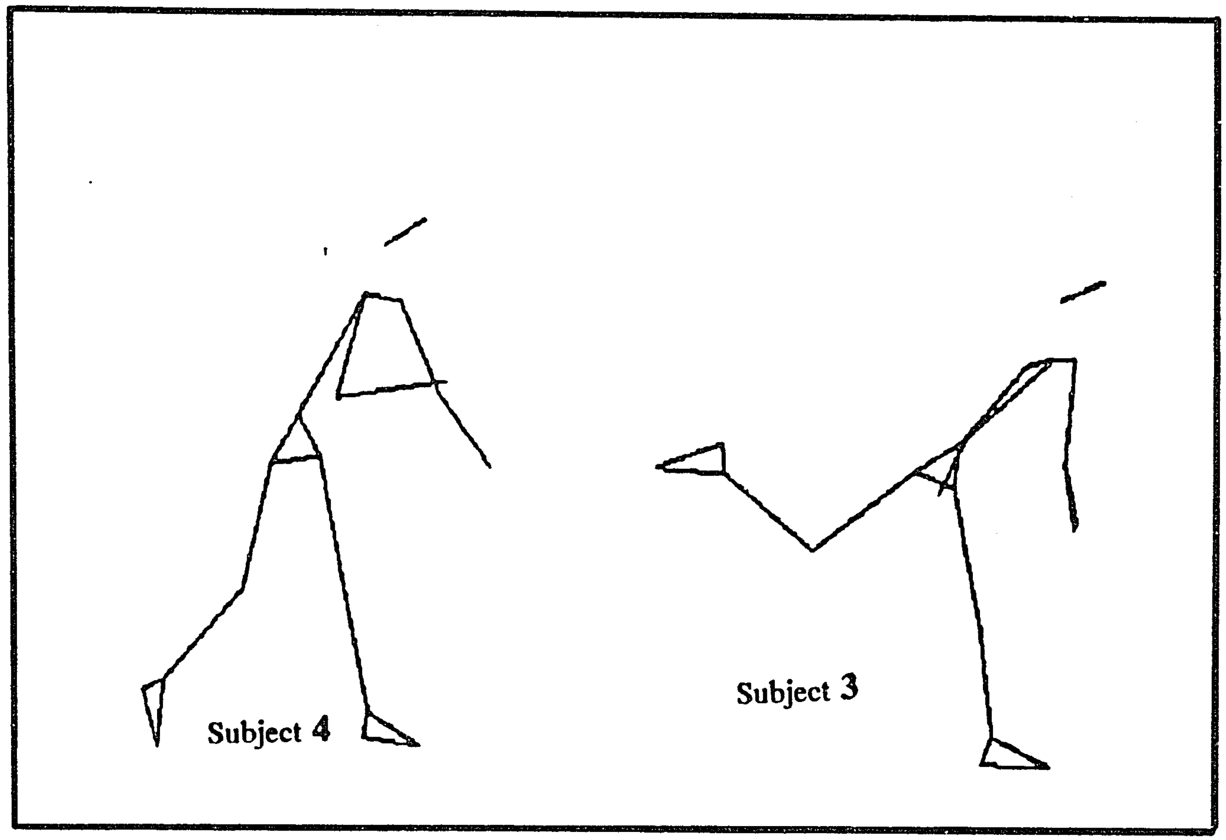


Figure 34. The degree to which the back foot is raised off the ground during the followthrough, two subjects.

Recommendations

Based on the present investigation there are six recommendations that need to be addressed in future research.

1. A video speed faster than the 60 fields per second used in the present study should be used in future research. For greater validity and a stronger concentration on timing, faster film/video speed is necessary.
2. Future research should investigate and/or compare trunk orientation of the different overarm throwing skills. Specifically the optimal degree of lateral and anterior lean that produces the greatest velocity and greatest accuracy must be considered.
3. The relationship between the elbow extension angle and the load placed on the distal segment needs to be further investigated. Observation suggests that skills requiring little or no loading of the hand may allow near or full extension at the elbow, while skills requiring larger loads may decrease this angle.
4. Uniformity or standardization of computer analysis programs used in the interpretation of the data needs attention. An example of this need is evident in the fact that the ball velocities at release, degree of external rotation, and elbow extension angle were similar in three separate studies, but the rotation velocity of the shoulders and hips was quite different.
5. The degree to which the hips rotate toward the front facing position during various throwing skills needs to investigated further. In this study the hips rotated only approximately two thirds of the way toward the front. The amount of rotation of the different overarm throwing/striking skills needs to be investigated with regard too the variables of interest (speed, accuracy, or load).

6. Researchers need to expand the view, or focus, of their investigations from just the throwing arm to include the entire body. More information about the lower body is needed.

REFERENCES

Abdel-Aziz, Y. I. & Karara, J. M. (1971). Direct linear transformation: From comparator coordinates into object coordinates in close-range photogrammetry. Proceedings ASPUI Symposium on Close-Range Photogrammetry, Urbana, Illinois (pp. 1-19). American Society of Photogrammetry, Falls Church, VA.

Adrian, M. J. & Cooper, J. M. (1989). The biomechanics of human movement. Indianapolis: Benchmark Press.

Atwater, A. E. (1970). Movement characteristics of the overarm throw: A kinematic analysis of men and women performers. Unpublished doctoral dissertation, University of Wisconsin, Madison.

Atwater, A. E. (1979). Biomechanics of overarm throwing movements and of throwing injuries. Exercise and Sports Science Reviews, 7, 43-85.

Boucher, J. P., Flieger, M. S. (1983). Signal characteristics of EMG: Effects of ballistic forearm flexion practice. In D. A. Winter, R. W. Norman, R. P. Wells, K. C. Hayes, & A. E. Patla (Eds.), Biomechanics IX-A (pp. 297-301). Champaign: Human Kinetics.

Bowne, M. E. (1956). The relationship of selected measures of acting body levers to ball-throwing velocities. Unpublished doctoral dissertation, University of Wisconsin.

Carlson, R. E. (1962). Analysis of the forward pass. Unpublished master's thesis, Washington State University, Pulman, WA.

Cavanagh, P. R. (1990). Biomechanics: A bridge builder among the sport sciences. Medicine and Science in Sports and Exercise, 22(5), 546-557.

Collins, P. A. (1960). Body mechanics of the overarm and sidearm throws. Unpublished master's thesis, University of Wisconsin.

Cooper, J. M. & Glassow, R. B. (1972). Kinesiology. Saint Louis: C. V. Mosby.

Elliott, B., Grove, J. R., Gibson, B., & Thurston, B. (1988). A three-dimensional cinematographic analysis of the fastball and curveball pitches in baseball. International Journal of Sport Biomechanics, 2, 20-28.

Feltner, M. & Dapena, J. (1986). Dynamics of the shoulder and elbow joints of the throwing arm during the baseball pitch. International Journal of Sports Biomechanics, 2(4), 235-259.

Feltner, M. E. (1984). Kinetic and kinematic parameters of the shoulder joint during the overarm baseball throw. Unpublished master's thesis, Indiana University, Bloomington.

Feltner, M. E. (1987). Three-dimensional segment interactions of the throwing arm during overarm fastball pitching in baseball. Unpublished doctoral dissertation, Indiana University, Bloomington.

Feltner, M. E. (1989). Three-dimensional interactions in a two-segment kinetic chain. Part II: Application to the throwing arm in baseball pitching. International Journal of Sports Biomechanics, 5, 420-450.

Gainor, B. J., Piotrowski, G., Pugl, J., Allen, W.C., & Hagen, R. (1980). The throw: Biomechanics and acute injury. American Journal of Sports Medicine, 8(2), 114-118.

Gowitzke, B. & Waddell, D. B. (1979). Qualitative analysis of the badminton forehand smash as performed by international players. In J. Groppel (Ed.), The racquet sports (pp. 1-15). Champaign: University of Illinois Press.

Greenisen, M. C., Gross, D., Madhill, H., & Marshall, M. (1973). Inquiry avoidance reflex during high-velocity throwing. Biomechanics: Abstracts of the fourth

International Seminar. Pennsylvania State University, August 26-31, p. 29. (Abstract).

Hang, Y. (1981). Little league elbow: A clinical and biomechanical study. In H. Matsui & K. Kobayashi (Eds.), Biomechanics VII-A (pp. 70-85). Champaign: Human Kinetics.

Hay, J. G. (1985). The biomechanics of sports techniques. Englewood Cliffs, NJ: Prentice-Hall.

Hinkle, N. (1979). How the laws of physics apply to throwing a football. Coaching Clinic, 17, 14-17.

Horn, T. S. (1984). An analytical solution to the determination of resultant joint forces and torques occurring at the shoulder joint during baseball pitching. Unpublished master's thesis, Auburn University, Auburn, AL.

Jensen, C. R., Schultz, G. W., & Bangerter, B. L. (1983). Applied kinesiology and biomechanics. New York: Mc Graw-Hill.

Jobe, F. W., Tibone, J. E., Perry, J. & Moynes, D. (1983). An EMG analysis of the shoulder in throwing and pitching: A preliminary report. American Journal of Sports Medicine, 11(1), 3-5.

Jobe, F. W., Tibone, J. E., Perry, J. & Moynes, D. (1984). An EMG analysis of the shoulder in pitching: A second report. American Journal of Sports Medicine, 12 (3), 218-220.

Kendall, F. P. & McKreary, E. K. (1983). Muscles: Testing and function. Baltimore: Williams and Wilkins.

Komi, P. V. & Mero, A. (1985). Biomechanical analysis of Olympic javelin throwers. International Journal of Sport Biomechanics, 1, 139-150.

Kreighbaum, E. & Barthels, K. M. (1990). Biomechanics: A qualitative approach for studying human movement. New York: Burgess Publishing.

Kunz, H. (1974). Effects of ball mass and movement pattern on release velocity in throwing. In R.C. Nelson & C.A. Morehouse (Eds.), Biomechanics IV (pp. 163-168). Baltimore: University Park Press.

Lindner, E. (1971). The phenomenon of the freedom of lateral deviation in throwing. J. Vredenbregt & J. Wartenweiler (Eds.), Biomechanics II (pp. 240-245). Baltimore: University Park Press.

Menzel, H. J. (1987). Transmission of partial momenta in the javelin throw. In B. Jonsson (Ed.), Biomechanics X-B (pp. 643-648). Champaign, IL: Human Kinetics.

Michaud, T. (1990). Biomechanics of unilateral overhand throwing motion: An overview. Chiropractic Sports Medicine, 4(1), 13-26.

Mikszewski, J. C. (1968). A comparison of direction and distance on the accuracy of roll-out passing. Unpublished master's thesis, Springfield College, Springfield, Mass.

Miller, N. R., Shapiro, R., & McLaughlin, T.M. (1980). A technique for obtaining spatial kinematic parameters of segments of biomechanical systems from cinematographic data. Journal of Biomechanics, 13, 535-547.

Montour, G. (1979). Teaching baseball pitching mechanics: A photographic essay. Coach and Athlete, 44, 19-22.

Morehouse, C. E. & Cooper, J. M. (1950). Kinesiology. St. Louis: C.V. Mosby.

Pappas, A. M., Zawacki, R., & Sullivan, T. J. (1985). Biomechanics of baseball pitching: A preliminary report. American Journal of Sports Medicine, 13(4), 216-222.

Peak Performance Technologies Inc. (1990). Peak 3D Motion Measurement module: User's reference manual, Version 1.7.0.0., Englewood, CO.

Pedegana, L. R., Elsner, R. C., Roberts, D., Lang, J., & Farewell, V. (1982). The relationship of upper extremity strength to throwing speed. American Journal of Sports Medicine, 10, 352-354.

Rash, G. S., & Shapiro, R. (in press). A three dimensional dynamic analysis of the quarterback's throwing motion in american football. International Journal of Sport Biomechanics.

Sakaris, J. D. (1978). Biomechanical analysis of overhand and sidearm fastball pitching techniques in baseball. Unpublished master's thesis, University of Florida, Gainsville.

Schnellenberger, H. (1984). The Miami passing game. Telecoach (Ed.), Coach of the Year Clinic Manual. (pp. 244-252). Louisville: Telecoach.

Selin, C. (1959). An analysis of the aerodynamics of pitched baseballs. Research Quarterly, 30(2), 230-240.

Shapiro, R. (1978). Direct linear transformation method for three-dimensional cinematography. Research Quarterly, 49, 197-205.

Sisto, D. J., Jobe, F. W., Moynes, D. R., & Antonelli, D. J. (1987). An electromyographic analysis of the elbow in pitching. American Journal of Sports Medicine, 15, 260-263.

Tarbell, T. (1971). Some biomechanical aspects of the overarm throw. In J.M. Cooper (Ed.), Selected topics in Biomechanics. Proceedings of the C.I.C. Symposium on biomechanics (pp. 71-81). Chicago: The Athletic Institute.

Toyoshima, S., & Miyashita, M. (1973). Force-velocity relation in throwing. Research Quarterly, 44, 86-95.

Toyoshima, S., Hoshikawa, T., Goya, T., & Matsui, H. (1981). Biomechanical analysis of throwing in twins. In H. Matsui & K. Kobayashi (Eds.), Biomechanics VIII-B (pp. 683-687). Champaign: Human Kinetics.

Toyoshima, S., Hoshikawa, T., Miyashita, M. & Oguri, T. (1974). Contribution of the body parts to throwing performance. In R.C. Nelson & C.A. Morehouse (Eds.), Biomechanics IV, Baltimore: University Park Press.

Tullos, H. S., & King. J. W. (1973). Throwing mechanism in sports. Orthopedic Clinics of North America, 4(3), 709-720.

Vaughn, R. E. (1985). Three dimensional kinematics of the baseball pitch. In J. Terauds & J.N. Barham (Eds.), Biomechanics in Sports III (pp. 72-78). Del Mar, CA: Academic Publishers.

Verduzco, M. A. (1991). The biomechanics of the quarterback position: An integrated approach. Unpublished master's thesis, San Jose State University.

Walsh, B. (1978). Quarterback-receiver coordination. West Coast Coach of the Year. (Available from Bob Troppmann 6 Key Largo Cove Corte Madera CA 94925).

Walsh, B. (1981). Controlling the ball with the passing game. In D. Herbert Football Coaching. (pp. 85-93). New York: Scribner's.

Wick, M. A., Dillman, C. J., Werner, S., Fleisig, G., Wisleder, D., Lemak, L. J., & Andrews, J. R. (1991). A kinematic comparison between baseball pitching and football passing. Sports Medicine Update, 6(2), 13-16.

Yessis, M. (1984). Throwing the football. National Strength and Conditioning Association Journal, 4(2), 6-8, 71-72.

Appendix A

Agreement to Participate in Research

Responsible Investigator: ROBERT HEPPE

Title of Protocol: The Kinematics variables related to the efficiency of Throwing: Football

Subject:

I have been asked to participate in a research study investigating the kinematic variables involved with throwing a football. I will be asked to wear lycra type shorts and have specified joints marked with paint and be video taped while dropping back and throwing to a target. Aside from minor discomfort due to possible weather conditions, no foreseeable risks or discomforts are anticipated. I understand that no direct benefits to myself are expected, although the video tapes and resultant data are available to me at any time. I understand that the results of this study may be published but no information that could identify me will be included unless I so authorize. However, the researcher may keep the video tapes for his own purposes. Questions about this study may be addressed to the principal investigator, Robert Heppe (408-476-7535). Complaints about this study may be presented to the Human Performance Chair (James Bryant, 408-924-3010). Questions or complaints about research, subjects' rights, or research related injury may be presented to Serena Stanford, Ph.D., Associate Vice President of Graduate Studies and Research, at (408) 924-2480. I understand that if I choose not to participate in this study no services of any kind, to which I am otherwise entitled, will be lost or jeopardized. My consent to participate in this study is given voluntarily. I may refuse to participate in the study or in any part of the study, and if I decide to participate in this study, I am free to withdraw at any time without prejudice to my relations with San Jose State University or any other participating institutions. I acknowledge that I have received a signed and dated copy of the consent form.

- **The signature of a subject on this document indicates agreement to participate in the study.**
- **The signature of a researcher on this document indicates agreement to include the above named subject in the research and attestation that the subject has been fully informed of his or her rights.**

Subject's Signature — Date

Investigator's Signature — Date

Appendix B

SJSU SAN JOSE STATE UNIVERSITY

A campus of The California State University

Office of the Academic Vice President • Associate Academic Vice President • Graduate Studies and Research
One Washington Square • San Jose, California 95192-0025 • 408/924-2480

To: Robert Heppe, Human Performance
4815 Rivervale Drive
Soquel, CA 95072

From: Serena W. Stanford *Serena W. Stanford*
AAVP, Graduate Studies and Research

Date: January 23, 1992

The Human Subjects-Institutional Review Board has approved your request to use human subjects in the study entitled:

"The Kinematics Variables Related to the Efficiency of Throwing: Football"

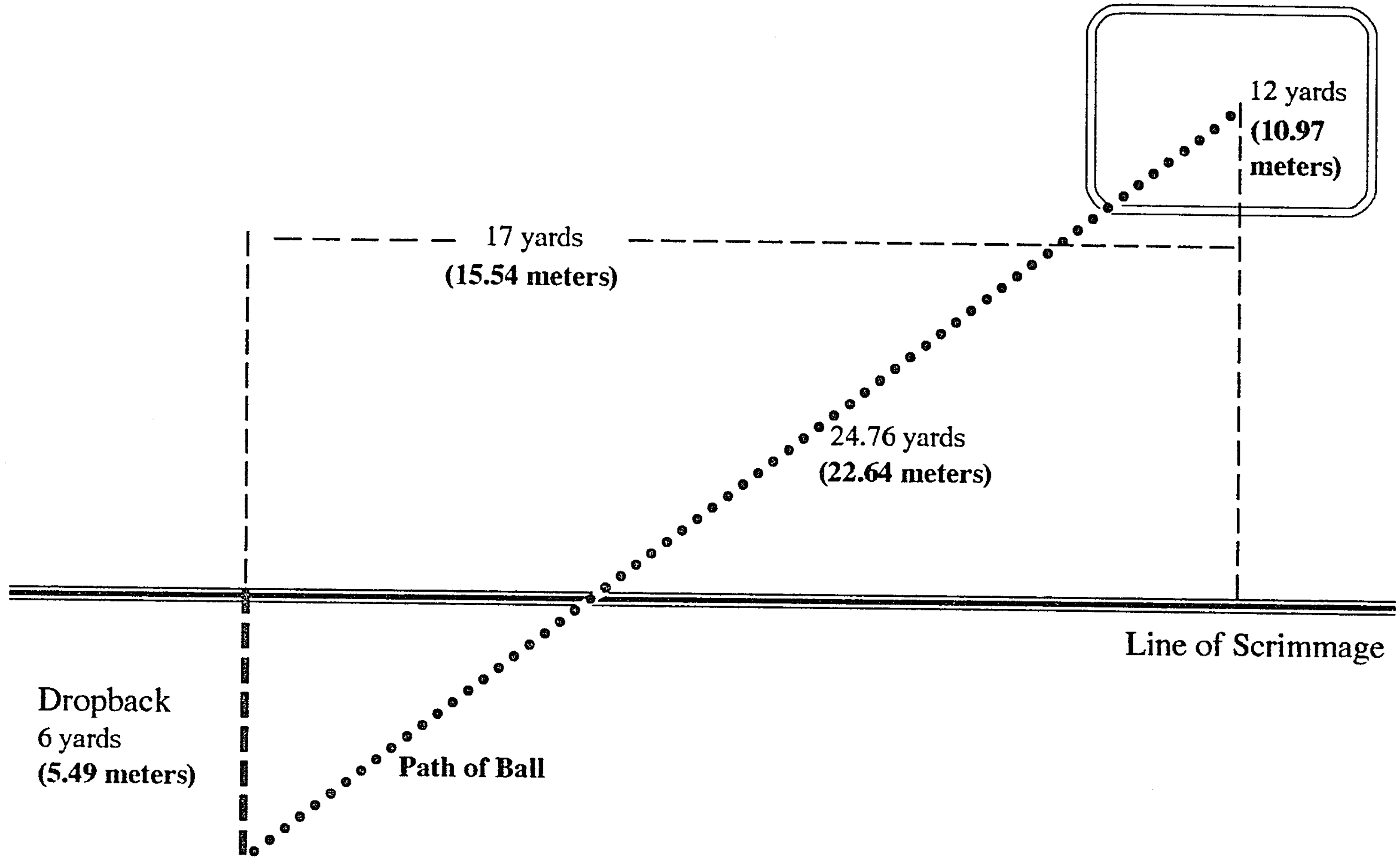
This approval is contingent upon the subjects participating in your research project being appropriately protected from risk. This includes the protection of the anonymity of the subjects' identity when they participate in your research project, and with regard to any and all data that may be collected from the subjects. The Board's approval includes continued monitoring of your research by the Board to assure that the subjects are being adequately and properly protected from such risks. If at any time a subject becomes injured or complains of injury, you must notify Dr. Serena Stanford immediately. Injury includes but is not limited to bodily harm, psychological trauma and release of potentially damaging personal information.

Please also be advised that each subject needs to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate or withdrawal will not affect any services the subject is receiving or will receive at the institution in which the research is being conducted.

If you have questions, please contact me at 408-924-2480.

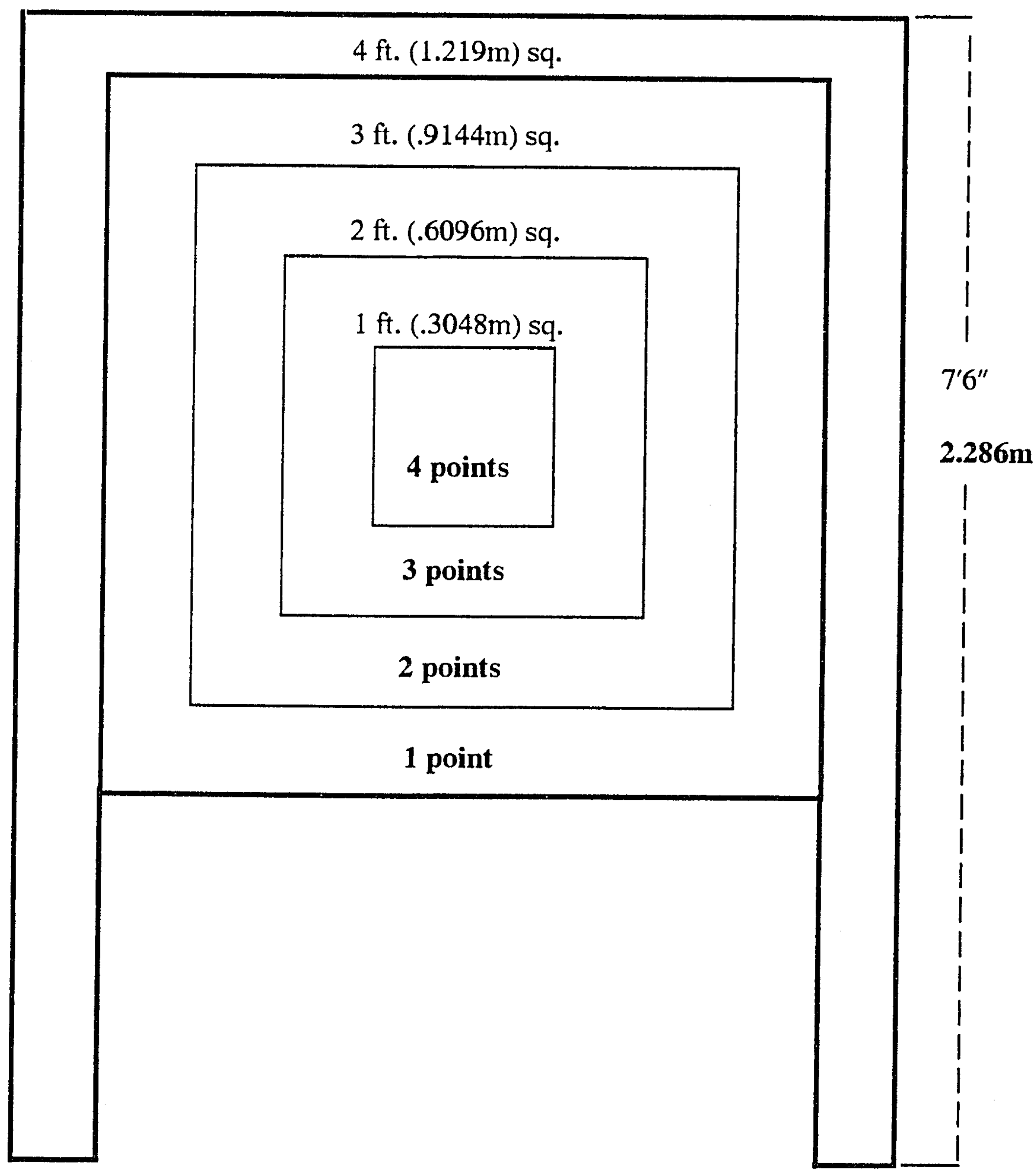
CC: Gail G. Evans, Ph.D.

Appendix C



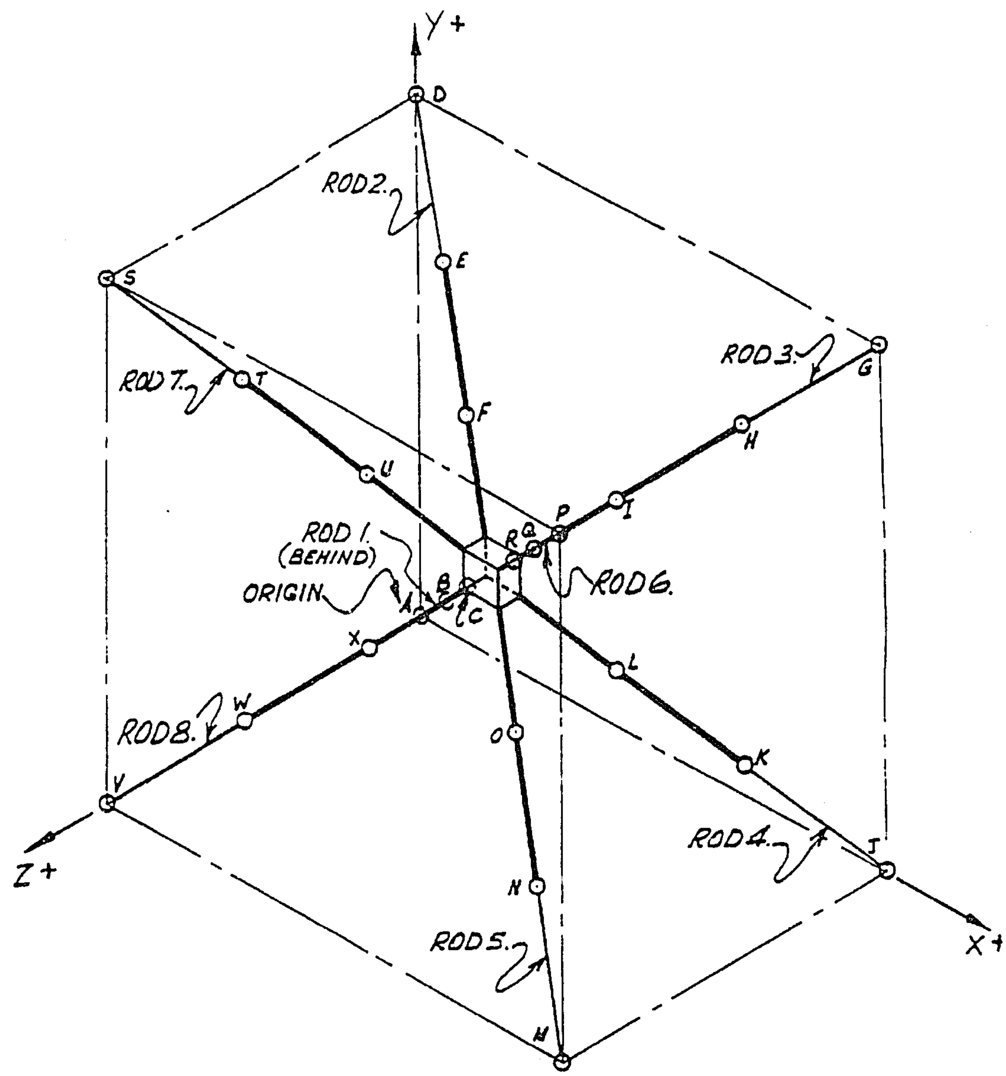
Taget Setup

Appendix D



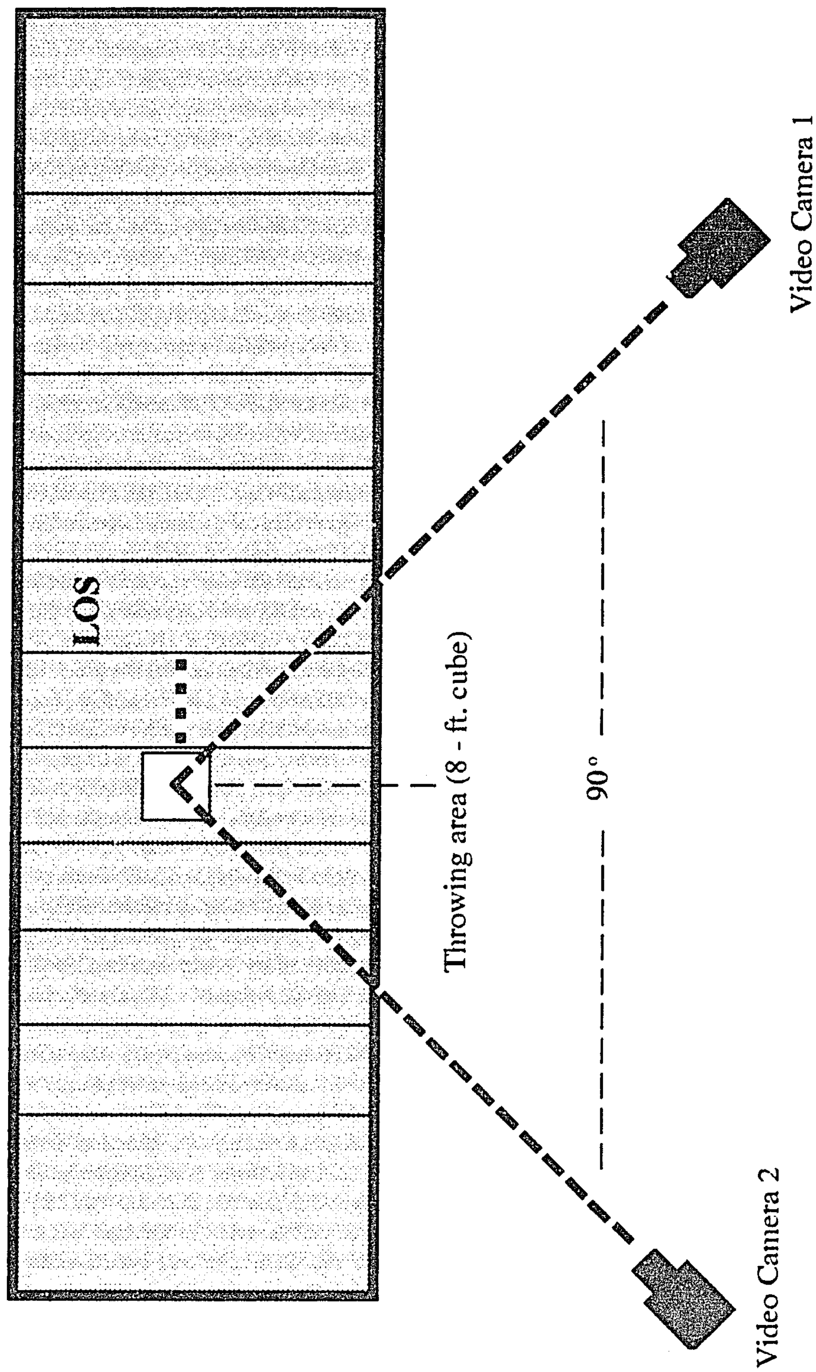
The Target - Dimensions and Point Value

Appendix E



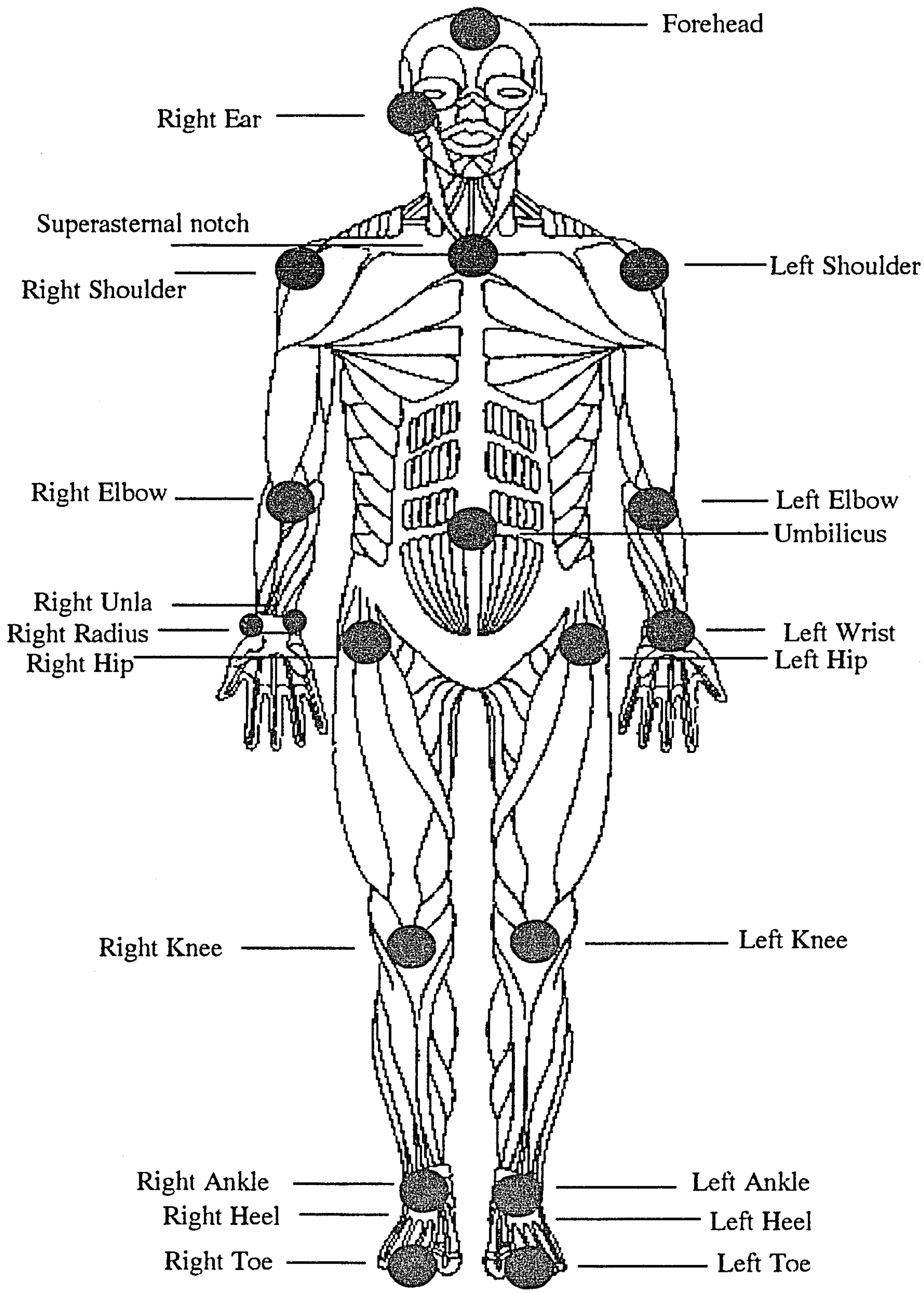
Peak Performance 3-D Motion System Calibration Frame (Peak Performance Motion System Manual, 1990) (Used by permission).

Appendix F



Video Camera Locations

Appendix G



Body Landmarks